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# SEEING
*And*
# HUMAN WELFARE

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Seeing—A Partnership of Lighting and Vision (with Frank K. Moss), 1931

# SEEING
*and*
# HUMAN WELFARE

*by*

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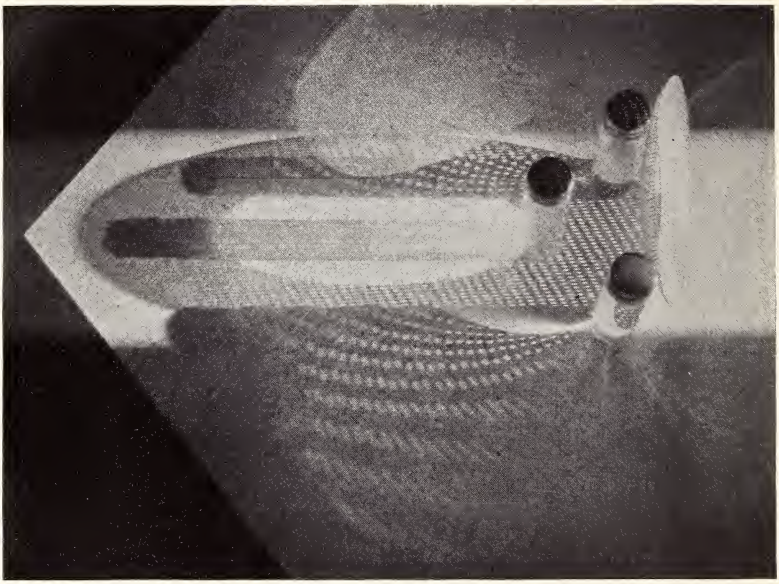


Seeing is a complexity of images and impressions which determine the efficiency, welfare and behavior of human beings. The external objects are a complexity of highlights, shadows, details and backgrounds which are greatly influenced by lighting. The internal results are deeply hidden in a psycho-physiological complexity. In unraveling these complexities the new science of seeing is revealing how the waste of human resources may be reduced.

# FOREWORD

Civilization has lifted burdens from the backs of human beings, but it has greatly increased the severity of visual tasks. Unnatural or abnormal demands are being met by human seeing-machines under unnatural or subnormal conditions for seeing. Human resources—eyesight, energy, health and even lives and limbs—are being unnecessarily sacrificed through lack of consciousness and knowledge of seeing. A new science of seeing has recently extended the viewpoint of vision into an activity involving human beings and their efficiency, behavior, resources and welfare. To the obvious *value* of seeing has been added knowledge of the subtle *costs* of seeing to human beings.

A science of *vision* has long been developing, but this deals with eyes and the visual sense which are *tools*. By means of such knowledge eye specialists have conserved and corrected eyesight. Eye-glasses counteract effects of heredity, age and *abuse;* they do not deal with causes. A *science of seeing* was badly needed in a half-seeing world in which little was known about seeing and the factors involved. It was natural for such a science to originate and develop in a laboratory

devoted to researches in the realm of light, radiation and human welfare. Our viewpoint gradually extended from lighting and vision as tools, to seeing as an activity of human beings operating as human seeing-machines. Eventually, the researches of the author and his colleagues, particularly Mr. Frank K. Moss, have laid the foundation of the new science of seeing and are revealing deeply hidden effects of seeing which are unnecessarily wasting human resources.

A complete sketch of seeing is presented herewith for the first time in a non-technical manner. Perhaps no controllable activity of human beings is of such universal importance as seeing. Certainly this little volume treats a subject from which none but the unfortunately blind can escape during most of the hours of living. The subject is intimately interwoven with living and is nearly as universal and complex. Its importance to any individual increases as responsibility for the welfare of other eyes and other human seeing-machines increases. Parents and employers, school authorities and the medical profession, social workers and safety councils can extend their good services further in the realm of seeing. The importance assumes even greater magnitude for those who play a wholesale part in the visibility of things. Among these are oculists, optometrists, lighting specialists, architects, decorators; also

producers of eye-glasses, light-sources, lighting equipment, paint, paper and printing. In fact, everyone can play a part in conserving human resources by developing a *seeing-consciousness*, which is the most important factor in the relationship of seeing and human welfare.

M. Luckiesh.

*April, 1934.*

# CONTENTS

CHAPTER I

This Half-Seeing World ..... 1

CHAPTER II

The Human Seeing-Machine ..... 21

CHAPTER III

The Science of Seeing ..... 44

CHAPTER IV

Visibility of Objects ..... 70

CHAPTER V

Eye-Defects of Age and Usage ..... 103

CHAPTER VI

Light and Lighting ..... 136

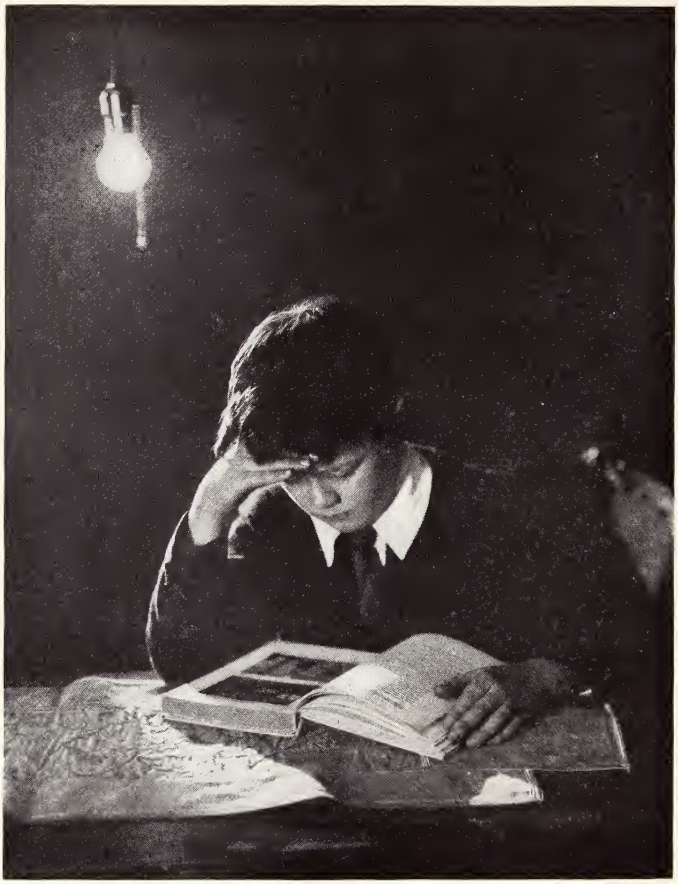
CHAPTER VII

Human Seeing-Machines at Work ..... 168

CHAPTER VIII

Suggestions for Further Study ..... 187

Index ..... 191



A half-seeing world has been grossly penalized because of its own lack of a seeing consciousness and because, until recently, a science of seeing was not available. With the advent of the new science of seeing, the idea of seeing easily is permeating a civilization which has been satisfied to barely see. Many hidden penalties have already been revealed.

## Chapter I

# THIS HALF-SEEING WORLD

An unusual experience may unusually affect the life and health of an individual; but human beings in general are influenced most by commonplace factors. This is another way of stating the doctrine of evolution, which helps us to understand our physical selves and some of our behavior. Viewed biologically, we came indoors only yesterday. Eons of evolution in the natural world adapted our bodies, sense-organs, life-processes and even our mental life to the commonplace factors of the outdoors. We are more than children of Nature. We are her slaves in important fundamental respects. Our lack of knowledge makes us think we are free; but we are free only superficially. We build an artificial world and become its victims to some degree. As we add to our scanty knowledge, this fact is proved over and over again. With adequate knowledge our independence increases. We may even improve upon the natural world, because Nature is a compromise for many living things, life-processes and sense-organs. But these improvements must be based upon knowledge and are generally along the lines of convenience and comfort. For eons

to come there can scarcely be any declaration of independence on the part of fundamental life-processes, sense-organs and behavior.

This is a safe and proper attitude for considering any fundamental possession or activity of human beings. Eyes are our most complex and useful sense-organ. The visual sense is our most complex and useful sensory process. Seeing is our most universal and valuable controllable activity. Seeing is nearly as complex as living and it is responsible for most of our experiences and, therefore, knowledge; and for most of our usefulness and, therefore, happiness. We need only note what a calamity blindness is to prove that eyesight is perhaps our most highly prized possession. But most persons should think of blindness occasionally, for that should aid in overcoming indifference toward eyes and should stimulate them to understand seeing. The very commonplaceness of seeing renders it at once highly important and generally ignored. Considering its overwhelming importance to human beings, their relationships, and the world they have built, it is outstandingly and almost universally neglected and uncomprehended by human beings.

## POOR SEEING IS COSTLY

Marvelous as the eyes are, they are only tools. Seeing is a complexity consisting of the external

world of physical objects and factors and the intricate internal world of psycho-physiological effects. The eyes are tools and doorways between these two worlds. The end-products of seeing are human efficiency, behavior and welfare. Much of the energy which we expend between arising and bedtime is used in the process of seeing. Much of the air we breathe and the food we eat is expended in seeing without any apparent physical work. Much of the fatigue in this half-seeing world of civilized beings is due to seeing. This represents an unknown and unsuspected cost of seeing, to which may be added the obvious costs of poor seeing in lives, limbs, property, inefficiency, headaches, indigestion, dizziness, and impaired eyesight.

The commonplaceness of eyesight and seeing, through the indifference it engenders instead of the importance it should bestow, is responsible for an enormous waste in human and material resources. During the World War the casualties in the American army touched many homes directly. Still, in normal times the annual casualties due to poor seeing in the every-day peaceful activities in this country exceed the total number of casualties in the American army during its participation in the World War. Spoilage of products in our industries and property damage on our streets due to poor seeing amount to many millions annually.

Every few minutes a person is accidentally killed in this country. How many of these are due to poor seeing? Studies indicate at least one-fifth of them. And a more critical analysis from the newly extended viewpoint of seeing shows this estimate to be conservative.

Nearly one-half the total number of adults in this country have defective eyes. By the time children become adults, about one-fourth of them exhibit eye-defects. These are so commonplace that they do not arouse attention. But suppose that crippled eyes could be transformed into crippled legs. What a heart-rending parade we would witness on a busy city street! Nearly every other person would go limping by. Many would be on crutches and some in wheel-chairs. How many of the defects of eyes are due to poor conditions for seeing, that is, to indifference toward seeing? Statistics are unavailable, but a knowledge of seeing and its requirements indicates that most of them are preventable and most of the remainder can be improved or arrested by adequate and proper conditions.

Crippled eyes need not be accepted as inherent to human beings and civilization any more than crippled legs need be. Both are due chiefly to neglect or ignorance. A baby is born with tiny legs and fairly well developed eyes. Usage develops the legs and generally they become normal

healthy adult legs without defects. Why should not the eyes develop into normal healthy adult eyes without defects? Certainly this is Nature's way. The difference must be found in abuse of the eyes, in the artificial world, but not of the legs.

Let us return to the natural environment under which human beings evolved. Various common factors are found which emphasize again the enormous influence of commonplace factors. Also, they throw some light upon the deficiencies and abnormalities of the artificial world of which we, as Nature's children, become victims. A fish cannot live out of water, because this is too great a change in environment. In the indoor world we are not fish out of water; but, to continue the analogy, the water is not always fresh and abundant.

Viewing the natural world by the side of Aristotle, we might agree with him that earth, air, water and sunlight seem to be the primordial elements under which life developed and human beings eventually evolved. Already, we know that natural light is essential to life and, considering that it showered upon the earth throughout the eons of evolution of living things, it must be intricately woven into life-processes in many ways. Beginning with the simplest organisms which are all eyes, all ears, all stomach, etc.,

sense-organs began to evolve or to become differentiated.

Eventually, the marvelous eyes of human beings were the result of the environment and of the need of human beings. They utilized the one element—light—which could travel quickly from objects at a distance. They are radio receiving-sets which respond to radiant energy of a certain range of wavelengths or frequencies emitted by the sun. They are selective to the wavelengths of energy which are most abundant in sunlight. Through eons of evolution they naturally became best adapted to utilize the light available. The optical system of the eye focuses this light upon the retina. Nerve activity brings the message to the brain-centers and a chain of happenings results in perception of an object *at a distance.*

The radio analogy is at once understandable and perhaps quite interesting. But the most marvelous fact is generally overlooked because of its commonplaceness. Why do we see the object out in space where it is, instead of in the eye where the image of the object is? The answer is that this is an acquired accomplishment. We have learned that the objects are out there and various factors, unconsciously appraised by us, tell us about how far distant the object is. We learned in our early infancy to see the object out in space where it is, instead of in our head, where

its image actually is. No other phase of seeing so emphasizes the complexity of this activity and establishes the importance of the psychological aspects as the perception of objects apparently where they are in the external world.

In further investigating the factors of the natural world, which have a bearing upon seeing, look at the physiognomy of the human face. Regardless of race and geographical home, all human beings evolved under Nature's lighting, which consists of a large expanse of bright sky and an intensely bright sun. The forehead projects for protection to the eyes and this includes partially shading them from the ever-present brightness overhead. The commonplaceness of these factors brought this about during ages of evolution.

The sun is so intensely bright that we avoid it. Artificial light-sources are glaring and should be screened from the eyes; but they are not bright enough to compel us to avoid them. As a consequence, until a consciousness of the desirability of shading them or of diffusing the light is awakened, human beings are abused and distracted by glare.

Almost everywhere one finds persons engaged in visual tasks with light-sources glaring at them. These abuses take their toll from human beings, sometimes openly but usually subtly. This de-

fect of lighting, which can be so easily corrected, has been wrongly interpreted as too much light. It is not this; it is light out of place. As is shown throughout this discussion, the artificial world of half-seeing human beings is very inadequately and usually improperly illuminated. The extremely meager quantity of light is the chief reason for the generally poor seeing conditions throughout civilization, although there are many other neglected factors.

Light is essential to seeing. It is the most important partner of eyes. In our indoor world, which is material civilization, we look back upon the age of candles and flickering oil-lamps as marks of a primitive age. If we are obliged to return to the candle through a mishap in distribution of electricity or in camp in the woods, reading is considered a difficulty. The quantity of light upon a printed page one foot from an ordinary candle is termed a *footcandle*. This has become the unit of intensity of illumination, just as a quart is a unit of liquid quantity. Most persons, ordinarily indifferent to seeing, would shudder at the thought of reading or performing other visual tasks one foot from an ordinary candle. However, most persons do this daily even under modern efficient convenient electric light.

Everywhere throughout the indoor world by

day and by night millions of persons read and work under intensities of illumination even less than one footcandle. Ten footcandles, or the equivalent of the intensity of illumination one foot from a group of ten candles, is unusual and is erroneously thought to be good lighting. Still, outdoors in the sun at midday there are nearly 10,000 footcandles, an intensity of illumination equivalent to that at one foot from 10,000 candles. In the shade of a tree, where we like to read, the intensity of illumination is often 1000 footcandles. Three feet from a 100-watt tungsten-filament lamp, the intensity of illumination is only about ten footcandles or about the same as that one foot from ten candles. This is only one per cent of the quantity of light in the shade of a tree. Millions of persons daily read the fine print of newspapers under intensities even less than one thousandth that in the shade of a tree in the summer time. And just because eyes can see under these conditions, this primitive condition is accepted. Can any one doubt that such enormous transgressions from natural conditions do not take heavy toll in human resources?

The distribution of brightness and color outdoors is another important factor which has left its imprint upon human beings. Esthetic and, more broadly, psychological effects are subtle. They are complex and not easily recognized, ana-

lyzed or understood. But the effects upon us are none the less real. We can be hurt through psychological channels as well as through physical agencies. We may not be thoroughly conscious of these abuses, but they leave their marks upon us physically and mentally. The monotony of the plains is written in the faces, attitude and lives of the inhabitants. The commonplaceness of the monotony of the landscape and of isolation leaves its imprint in many ways. Likewise, the squalor of the slums, as well as the esthetic environment of the more fortunate, does much to mould the outlook and, consequently, the lives of people. When we turn to Nature's distribution of brightness and color, we find many clues to our practices and reactions in the artificial world. What is natural, in its important fundamentals, is more satisfying and easier to live with than what is unnatural.

### NATURE'S PSYCHOLOGICAL INFLUENCES

Human beings are products of natural environment, psychologically as well as physically. It is true that we are less stable mentally than we are physically. The human race would have to walk on its hands for eons before the eye-protective devices, such as eye-brows and projecting forehead, would be developed on the side opposite their present location. On the other hand, psy-

chological alterations can take place relatively quickly. An aversion to brown clothes can be developed from having to wear a brown suit too long. Changes in mental attitude, which are connected with physiological effects, are common. One may become sick of this food or that drink under certain conditions and the aversion and its associations suddenly arise and last indefinitely.

Notwithstanding this lesser stability of psychological reactions, natural environment has left its effects firmly imbedded in everyone. Who does not respond to the cheerfulness of a sunny day? It enlivens the step and the attitude. Who is not influenced by the overcast sky? It is true that the associations of these weather conditions are partially responsible for their effects; but this does not alter the fact that they are psychologically effective. Still, fundamental laws of naturalness are universally transgressed indoors.

Outdoors the sky is very generally the brightest large area in a landscape. The brightness generally decreases from the sky downward through the middle distance and into the foreground. In decorative schemes indoors this naturalness has prevailed because it is natural. The unnatural can be effectively used for special purposes, but it is not satisfactory to live with. Through neglect, indifference and ignorance, indoor environments are often depressing and dis-

tracting. No one can escape the effects of these whether they are conscious of them or not. Eyes are the doorways of impressions and seeing is a vast parade of experiences. Decorative schemes and lighting produce much of the environment which may readily be restful or enlivening to the benefit of human beings.

The visual sense utilizes natural light in such a manner that the light appears approximately white. Is it not natural that continued adaptation has made natural light appear colorless to human eyes? Color is produced by objects which absorb energy of certain wavelengths, depending upon the color. The colors of Nature which occupy prominent areas produce certain psychological effects. Green is more or less neutral in this respect. Owing to its prominence in Nature, human beings have become so used to it that it is practically neutral. But red which is relatively rare in Nature and scanty in area is not neutral. It is stimulating, even hot, perhaps due to associations. Consider blue sky and the blue shadows of Nature's solitudes. Coolness and depression, respectively, are the results. Color in Nature is too complex for treatment here; but the reader can be assured that in natural environment are found the answers to many of the fundamental psychological and esthetic effects of colors as well as of lighting effects and brightness-

distributions. It is an absorbing subject and proper use of color, brightness, light and lighting are of considerable moment to human beings who would conserve their resources and foster their happiness.

### CIVILIZATION'S ABNORMAL DEMANDS

Civilization has lifted great burdens from the backs of human beings. It has harnessed natural laws and unharnessed human slaves. But, amid the clanking of the falling chains, the burden upon eyes and human seeing-machines silently and steadily increased. From relative ease and freedom they passed deeper and deeper into slavery. It is true that, in proportion to this enslavement, civilization and enjoyment advanced. No one would suggest that this has been an undesirable exchange. However, through neglect and ignorance the cost to human beings as seeing-machines is unnecessarily high. The avoidable waste has been and still is staggering.

Even a hundred years ago a large percentage of civilized persons could not read. Now nearly everyone can. A few centuries ago relatively few could read. A few thousand years ago none could read and few applied themselves to close visual work for long periods. Before that, human eyes, during ages of evolution of primitive beings and eons of evolution of their ancestral line, did close

work casually. Seeing objects at a distance was of more importance than viewing them within arm's length. A distance of twenty feet or greater is practically infinity as far as convergence of the eyes is concerned. Thus, civilization imposes unnaturally long periods of close work upon human beings. Herein is found the source of many eye-defects and bodily disorders. Herein is found the reason for much of the fatigue, nervous tension, muscular strain and waste of human resources written in the faces and health records of modern civilized human beings.

There is still another angle to this abnormal convergence of eyes over long periods daily. Convergence is not the natural state of rest for the eyes and concentration of attention is not the natural state of rest for the human seeing-machine or the mind. Not only were these severe conditions imposed upon the human race only yesterday, after ages of relatively casual effort in these directions, but babies continue to be born with distant vision. Convergence of eyes is an acquired ability. Babies must learn to do this to meet the later requirements of living. But certainly evolution, which eventually adapts the organism or its parts to new conditions, requires time. The few centuries of civilization during which great changes in the requirements of eyes and seeing have taken place are only a few ticks of

Nature's clock. Having almost endless time, she works slowly and inefficiently, but with certainty.

Contrary to common opinion, there is no proper or best distance for reading or performing other serious visual tasks as far as only the eyes are concerned. There is no scientific proof that near-vision is as easy upon human seeing-machines as far-vision. In fact, distant-vision beyond twenty feet, when the strain of convergence practically disappears, is the least strained condition and the natural one. The establishment of approximately 14 inches as the best distance for reading a book was not based solely upon consideration of the eyes. The length and ease of the arms have been great influences in this decision, whether recognized as such or not. These are justifiable considerations and practical ones. Likewise, the distance at which things can be easily held before the eyes has subtly, though irresistably, influenced the size and form of many things to be seen.

A page of printed matter one foot square is visually the same size at a distance of one foot as it would be when magnified ten times and viewed at ten feet. At ten feet the effort of convergence is greatly reduced. But looking at the matter practically, books ten feet square are costly and unwieldy—and who would turn the pages? Therefore, the sizes of type and pages, and the sizes of

many things, are dictated by using them and seeing them within arm's length. Within this distance there is a best and proper distance. When determined by seeing, the best distance is arm's length, if the type is large enough. When determined by comfortable position of the arms and hands, the distance must be shortened. Usually the type has been developed for a distance less than the length of the arms.

Inasmuch as visual size is proportional to the distance from the eyes, the visibility of small type is better when it is closer than when it is at arm's length. As the distance is lessened, the unnaturalness or strain of convergence rapidly increases. Therefore, when normal eyes are obliged to look at objects less than a foot away for long periods, unnecessary strain is experienced, which results in a waste of human resources. This is a cause of much of the nearsightedness developed in normal eyes.

Quantity of light or intensity of illumination is also a factor. When this is inadequate, as it very generally is, a printed page is held closer to the eyes. The resulting magnification of the printed matter, or increase in visual size, compensates to some extent for the inadequacy of light. However, this abnormal position causes nearsightedness. Perhaps most cases of the development of nearsightedness in young eyes, and of progressive

myopia (nearsightedness) in adult eyes, are directly traceable to holding the visual task too close to the eyes. Sometimes this is merely a habit; but usually it is due to the necessity of seeing fine details, commonly matter printed in small type, as exemplified by a newspaper, in inadequate light.

### A SEVERE DOUBLE PENALTY

At the same time that advancing civilization was increasing the severity of visual tasks and the periods during which close work was being done, the quantity of light was being restricted more and more. Nature's human beings who did close work rarely and casually had an abundance of light of a natural quality. The intensity of illumination at midday in midsummer has been nearly as high as 10,000 footcandles for eons. Objects outdoors reflect much less light than white paper and this high intensity of illumination was, and is, ideal for seeing natural objects. Even in the shade of a tree in midsummer, the intensity of illumination is about 1000 footcandles. For most persons the shade of a tree or porch is a good place to read a book, provided the eyes are shaded from the expanse of sky. Even under these conditions the white paper, which is a product of civilization, is less bright than leaves and most other objects in midday sunlight.

As civilization advanced, buildings greatly restricted the amount of light reaching tasks indoors. Human eyes and human seeing-machines eventually worked for long periods daily at unnaturally close work with the intensity of illumination only one thousandth and even one ten-thousandth of that outdoors. And the tasks grew more and more severe until now a vast variety of fine details must be discriminated which human beings did not bother about during the ages before yesterday in the life of the human race. Need one wonder why eyes are defective and other human resources are drained?

Many controllable factors in seeing can aid the human seeing-machine, if attention is given them from the viewpoint of a science of seeing which is beginning to be developed. But a seeing-consciousness is one of the most controllable factors. It does not exist; but many interests can aid in its development through their educational work—when these interests themselves have developed a seeing-consciousness. The greatest difficulty in developing this new viewpoint is to learn first of all that seeing does not mean eyes. Of course, eyes are important; but they are tools. The human being is the seeing-machine and seeing involves the external factors and psycho-physiological effects as well as the visual tools. Besides, the science of eyes or vision is well developed.

Oculists and optometrists do excellent work in sharpening these tools with glasses. But these tools and their owners must be followed out into their worlds, if the many abuses of eyes and of human seeing-machines are to be eliminated.

The prevalent assumption that when things can be seen the seeing is satisfactory must be shattered, for this is not true. How little is known of seeing and the factors involved is well illustrated by considering prevalent ideas in regard to light, which is an omnipresent factor in seeing. It is not uncommon to hear persons, even eye-specialists, say that there is too much light in a room. We have already made some comparisons which show that light in the indoor world relative to daylight outdoors is insignificantly low in quantity. In order to supply the artificial world as much light as Nature supplies in the natural world, each person would have to make as many electric lamps daily as are now being made daily in the entire world. One need not worry that the time will soon come when the artificial world will be overlighted.

Great improvements can be made in all the controllable factors in seeing, of which there are many. Often great improvements result from simple expedients and any person can do much to help himself to conserve his resources if he develops a seeing-consciousness. He owes it to himself,

his family and his associates in the work-world. There is a great need for improvement of seeing conditions everywhere and there can be no more important ideal where the efficiency, welfare and happiness of human beings are concerned. Emancipation of human eyes and human seeing-machines, enslaved and unnecessarily penalized by civilization, is a worthy cause in which everyone can enroll selfishly and generously.

Most of the researches, which provide the basis of the science of seeing as presented in these chapters, have been prosecuted by the author and his colleagues over two decades. However, only in recent years have our ideas of seeing and of the human seeing-machine become clear-cut. In the development of these the author gladly acknowledges the excellent work of Mr. Frank K. Moss, who has contributed much toward new methods and new knowledge.[1]

[1] Seeing—A Partnership of Lighting and Vision. M. Luckiesh and Frank K. Moss. Williams & Wilkins Co., Baltimore.

As human seeing-machines we are not merely concerned with seeing an object revealed by highlights, shadows and background. We are interested in the difficulty of seeing and the duration of the task. The science of seeing reveals the fallacy of momentary appraisals of seeing. It is concerned with the accumulative effects of seeing throughout the period of work. It has shown that the waste in energy and other human resources decreases as seeing is improved.

## Chapter II

## THE HUMAN SEEING-MACHINE

No other three words sketch the breadth and depth of the subject of seeing as well as the *human seeing-machine.* A view of the human being as a machine inevitably extends the consideration beyond the eyes. This is essential if one is to obtain an adequate conception of seeing. Eyes are important parts of the seeing-machine, and they can be abused, fatigued and damaged just as an important part of any machine can be. But the human being is entitled to the considerations any complete machine receives. The efficiency of a machine is measured by the ratio of the output to the input. The difference between the output and the input is the internal loss or useless work done. Certainly the efficiency of a human being is not properly measured by such terms as useful work per hour or per dollar. These do not take into account the wasted energy or the total work done as a machine. If a machine is misused or overworked, there is also a noticeable depreciation of some of its parts. Similarly, parts of the human being suffer from misuse. Therefore, the real cost to the human being in doing a given amount of useful work is the total work done,

which includes unnecessarily wasted energy and wear and tear on various parts. Scientific research has been developing methods and technique for measuring these factors. Already it is indicated that much of the waste of poor seeing can be eliminated and many new facts have been established.

Seeing has already been defined as a complex function and a complete activity of a human being instead of being merely the performance of eyes as visual tools. Seeing is much more than vision, because it is the complete operation of a human seeing-machine. It has been given little attention as an activity which consumes human resources, notwithstanding it is the most commonplace controllable activity of human beings. It is done as automatically as breathing. It is a common experience during early infancy. It is accomplished perhaps before it really is an experience, because it is done before thinking becomes a conscious act. Therefore, human beings emerge from the maze and haze of babyhood as used to seeing as they are to breathing. Certainly this is a clue to the general indifference toward seeing. Perhaps this partially explains why it has been neglected in scientific research. The movement of modern science did not overlook eyes and the visual sense; but it neglected to develop a science of seeing, notwithstanding the fact that no other science is more important to human beings.

After gaining a proper conception of human beings as seeing-machines, consideration must be given to a characteristic that no other machine has. The human seeing-machine is *human*. Cameras are seeing-machines; and, after a fashion, photo-electric cells are. But a human seeing-machine experiences feelings, enthusiasm, depression, nervous tension, muscular strain, digestive disturbances, headaches and many other psychological and physiological effects. All these are influenced by the severe visual work of modern civilization.

### SENSE CAPACITY AND ATTENTION

As one sits comfortably in a quiet room alone, reading a book or performing any other task of seeing, all his attention and sense capacity are devotable to the task. If one is worried or uncomfortable, some of his attention and sense capacity is not available for the task. In a noisy room a purely visual task cannot be performed as rapidly as in a quiet room. Distractions decrease the efficacy of seeing. Therefore, seeing conditions, which are barely satisfactory in the laboratory or under ideal conditions, are inadequate in the world of activity. Factors of safety are desirable under any conditions and are essential under usual conditions. But such factors are not considered, with the result that human seeing-machines are unnecessarily penalized.

It is easy for anyone to choose many examples from daily experience which illustrate the foregoing. Let us take the case of driving an automobile on a busy street. As the driver is approaching a cross-street, a traffic sign is waiting to warn or command him, but apparently he ignores it. The traffic-officer perhaps said to the driver, "Can't you see the sign?" Of course, the sign is now visible to the officer and the driver, both of whom have nothing to do for the moment but look at it. But the conditions were quite different for the driver before he stopped the automobile. At best, only a brief moment was devoted to it as his eyes swept the intersection. Much of his capacity for seeing was utilized by other objects. The traffic-sign was small and not conspicuous in the extensive visual field with its many forms and colors. Some of his sense capacity and attention was being used in operating the automobile, even though this seemed to be an automatic operation. Through his ears various sounds commandeered some of his sense capacity; and some attention was given to listening for warning sounds from the side-street. Subtracting all these, and more, one finds that very little of his attention and sense capacity was available for seeing the traffic-sign. Besides, only a brief period of time was available. Under such conditions, what is the visibility of the sign? Certainly,

it is low compared with the condition when it alone is commanding attention. Actually traffic signs which are not self-luminous, but merely painted, are of such low visibility as to be generally worthless.

Most visual work is done under distraction of some kind. Where manual and visual work are combined, only a part of the attention and sense capacity is available for seeing. Therefore, any improvement which makes seeing easier and quicker, increases certainty and conserves human resources. To the severity of unnatural visual tasks and the inadequate and often unnatural conditions of lighting, which civilization has imposed upon human seeing-machines, we may now add the distractions that are so common and their demands upon attention and sense capacity. As we go more and more deeply into the subject of seeing, we find handicaps added one after another. Certainly, they can account for the known cost of seeing and for a large suspected unknown cost.

### PRODUCTION OF USEFUL WORK

When work done by a worker is measured by the useful production which accumulates upon his desk or bench, or by what he accomplishes in return for his wages, his efficiency is determined from the viewpoint of the employer rather than

of the worker. Such a procedure considers the welfare of the employer, but not of the employee. As pointed out heretofore, the efficiency of the worker as a human seeing-machine has not been measured at all. The cost to this human machine, of doing the measured amount of work, remains unknown.

During recent eras of prosperity some study was given to the influence of quantity of light or intensity of illumination upon the production of useful work by workers. There are many other factors which improve seeing, and sometimes these are simple and inexpensive expedients; but light is always a necessary factor. Such studies have been made in offices and factories, but the most valuable from the viewpoint of understanding seeing are the controlled researches of the scientific laboratory. Invariably in these production tests outside the laboratory a condition is reached where production reaches practically a maximum; that is, where further increase in intensity of illumination results in no measurable increase in production. The intensity of illumination at which this practical optimum is reached depends upon the character of the task. It is much higher for purely visual tasks, such as reading, than for visually controlled work in which considerable manual work is involved. In fact, in highly controlled laboratory researches the increase in

production continues up to relatively high levels of illumination.

In the industrial researches usually the practical optimum is reached for intensities of illumination of 10 to 30 footcandles. Although these levels are considerably higher than the intensity of illumination one foot from a common candle, which is so commonly found even in this electrical age, they are still meager compared with the comfortable levels near an unobstructed window in the daytime or on a porch in the summertime. It is not the purpose to emphasize the results at this point, but rather to reveal the erroneous conclusion drawn from them. Almost universally it has been assumed that no further benefits could be obtained by using more light.

In tests on mail sorters it was concluded, as usual, that the level of illumination, at which the practical maximum of speed in sorting was reached, was an *adequate* intensity of illumination. These mail sorters had to read at high speed many addresses of low legibility, including scrawl, low-contrast typing, addresses through window envelopes and fine print on colored backgrounds. This task is a strenuous one in seeing. Still, it apparently occurred to none that still more light than that at which production ceased to increase appreciably might make the task *easier*. The idea of the human seeing-

machine had not been conceived at that time. More light, or an improvement of any other seeing factor, is now known to make the task easier, with a resulting decrease in the drain upon human resources.

With the development of the new idea of the human seeing-machine, the inadequacy of the production of useful work as a measure of seeing conditions becomes obvious and sometimes ridiculous. The injustice of such a measure arises from considering the cost of production to the employer, but not the cost to the employee. There is neither logic nor humanity in the conclusion that seeing-conditions cannot be improved beyond that point at which the natural maximum speeds of the worker's hands, arms, body, eyes, reactions and mind have been reached. Everywhere throughout the work-world human seeing-machines are still paying the penalty for that erroneous assumption and, worse still, for neglect and ignorance of the human seeing-machine.

A certain laboratory research, whose conditions have been experienced by most persons, illustrates the futility and injustice of judging seeing conditions by the rate at which productive work is done. Reading on a moving train or street-car can be done rapidly when the jolts are not too severe, but certainly not without annoyance and even discomfort. To study certain effects of

reading when the printed matter is vibrating, a rack was made to vibrate rapidly, with vertical and side-wise vibrations of small amplitudes and different frequencies superposed. Reading ordinary printed matter vibrating in this manner was a very severe visual task, so severe that after a fifteen-minute period eyes were inflamed. Some of the subjects suffered such discomfort that they declined to continue throughout the series of different periods necessary to obtain satisfactory averages. However, quite a number of subjects completed a series of tests extending over several weeks with a result which at that time was astonishing. Practically the same number of pages was read in a given time when the printed matter was vibrating as when stationary. Here were two tasks identical in all respects, excepting that the printed matter was vibrating in one case and was stationary in the other. In the one case the task was extremely annoying and even discomforting; in the other it was relatively very easy. On the basis of speed of reading or production of useful work, the seeing conditions would be rated approximately identical. Such a conclusion in this case is obviously unjust to the readers and actually ridiculous. Other examples could be cited to prove the inadequacy of old views and the need of the new extended viewpoint and a new deal for human seeing-machines.

A typical example involving fatigue, and an

attempt to appraise it, also reveals certain prevalent assumptions to be erroneous. Fatigue is a very difficult effect to measure. Even eye-fatigue has not been satisfactorily isolated or separated into its components; and, of course, general bodily fatigue is a summation of the results of various kinds of activities. The direct isolation of the general fatigue caused by seeing is a task which at present appears hopeless. However, by attacking this complexity in various direct and indirect ways, certain correlations with measurable factors are revealed and thus it is being partially unraveled.

A large number of subjects were tested before beginning work and at the end of the day over a period of many days. Their daily work consisted of serious visual tasks, such as stenography, reading and drawing. The average results after completing a day's work, compared with those at the beginning, showed evidence of eye-fatigue and strain; and, of course, each subject experienced the usual general fatigue resulting from a day's work. Notwithstanding this condition of fatigue, strain and nervous tension, the tests applied after the day's work was done showed a 4 per cent increase in the rate of performance of work and a 14 per cent increase in attentiveness to the task.

## PENALIZING WILLINGNESS

When extensive and highly controlled laboratory researches reveal conclusive evidence that workers, fatigued by a day's work, work faster and with greater concentration than at the beginning of the day, the futility of production as a measure of seeing is further emphasized. This result is typical of that obtained in other researches. It should be obvious that, when increased production is accomplished by workers whose ability to produce has been lessened by fatigue, there is a combination which, if ignored, may operate against the welfare of the workers. Neither is the rate of production nor the quality of work done a measure of seeing conditions or of the condition of the human seeing-machine at the close of a work-period. The clue to such results is found in the willingness of eyes and workers to draw upon their reserves to compensate for poor seeing and for fatigue. Runners draw upon reserves of energy and will-power in their closing sprints. In the cases of eyes and workers, they pay the price of willingness and reserve ability to sprint even at the finish. Both are penalized, because there is little or no evidence of the severity of the visual task in the records of production and because they do not complain directly, when taxed by prolonged abuses, until they approach the point of exhaustion.

The ability of human seeing-machines to apparently adjust themselves to a variety of conditions makes it difficult to obtain exact relationships between the factors which affect seeing and the results of seeing. This is an important reason why researches outside the laboratory are not very promising. But a common mistake in scientific research has been to confine measurements almost entirely to the thresholds of visual ability, that is, to the limiting conditions under which something is barely visible. The predominence of such results has made them the basis for practice and for many erroneous conclusions. With the development of the new viewpoint which is creating a science of seeing, optimum conditions are receiving attention. It is relatively easy to measure the limiting conditions of visibility, because these involve chiefly the factors of the external world. The determination of the best conditions for the human seeing-machine requires the development of new methods and technique and the measurement of psycho-physiological effects, such as fatigue, nervous tension, muscular strain and other complex effects. But much progress is being made.

### FACTORS OF SAFETY

Threshold or limiting conditions for barely seeing an object, obviously represent a situation in which the factor of safety is unity. Such a

situation means that there is nothing in reserve. If these conditions are determined under ideal conditions of the laboratory, a factor of safety should be provided to take care of the distractions and other demands upon the attention and sense capacity under the usual conditions of the work-world. Then, following the line of logic already presented in regard to the unnaturally close and prolonged work in the artificial world, an additional factor of safety is desirable to compensate for these impositions.

The limiting or threshold size of each member of a steel bridge can be computed; but the bridge is built with factors of safety many times unity or the point close to failure. Lack of appreciation of the necessity for an adequate factor of safety in seeing conditions is due largely to the fact that human seeing-machines can force themselves to operate over a great range of conditions and that the penalties are not obvious. An adequate factor of safety for seeing represents conditions under which seeing can be done quickly, comfortably, with great certainty, and with the least waste of human resources. The seeing conditions are not necessarily adequate when the work can be done with merely the required speed and precision. An adequate factor of safety takes into account ease of seeing and conservation of human resources.

Owing to the variety of visual tasks and seeing

factors, and to the lack of adequate development of the new science of seeing, it is impossible to give a general recommendation as to the magnitude of a desirable factor of safety. Actually, it must be very large to take care of many known requirements. However, the mere recognition of its necessity is a step toward understanding seeing and will do much to improve many deplorable conditions which are penalizing millions of human seeing-machines every day. In fact, it would be difficult to find a person doing serious visual work in the work-world, or reading at night in his home, under really adequate or ideal seeing conditions. Such conditions are rare in the artificial world.

### NERVOUS MUSCULAR TENSION

In the invasion of the realm of psycho-physiological effects of seeing, the most outstanding success so far has been made in measuring nervous muscular tension. This term is an arbitrary one for describing a combination of nervous tension and muscular strain. Scientific attack in this direction was the outcome of observations of human beings engaged in various kinds of tasks.

In driving an automobile along a country highway at a moderate speed one relaxes and is not particularly conscious of nervous or muscular tension. But when one enters a city where traffic

is dense one sits up straighter and grips the wheel more tightly. Seeing has now become more important on account of the numerous hazards and more difficult owing to the variety of demands upon attention and sense capacity.

A similar comparison can be obtained in night driving. On a well-lighted boulevard amid considerable traffic, one experiences less tension than after turning into a side street poorly illuminated, even though there may be little or no traffic.

Also, one may compare driving on a clear night with the difficulty of driving in a fog or rain. In the latter case one grips the wheel more tightly, leans forward, and peers intently through the wiped portion of the windshield. The nervous muscular tension is obvious and after an hour's driving fatigue is noticeable. One reaches his destination with relief.

A skilled boxer is on his toes physically and highly alert muscularly, neurally and mentally. He tires as much from nervous muscular tension as from physical effort.

One perspires in a cool room when he is under tension making his first speech, or in the cold open air if he is playing the football game seriously in his grandstand seat. After writing for hours one grips the pencil more tightly as he becomes fatigued.

Examples without end may be cited to illustrate

the prevalence and importance of nervous muscular tension. It indicates strain, fatigue, wasted effort and internal losses. All this means wasted human energy and unnecessary depletion of human resources. Of course, one can scarcely be alert and working at high speed without exhibiting such tension, but unnecessary waste is useless work and it can be lessened by improving seeing.

Inasmuch as nervous muscular tension is so universally exhibited in extreme cases of poor conditions of seeing, it has proved to be a new and excellent method for invading an important realm. The method need not be described excepting to state that in measuring psycho-physiological effects the subjects, insofar as is possible, must be kept unaware of the purpose of the investigation or of what is being measured. This often requires unique and elaborate recording apparatus.

The sensitivity of the method was first tested in connection with moderately glaring light-sources. The discomfort from these was no greater than that experienced with indifference by millions of persons daily who apparently do not possess even a slumbering seeing-consciousness. The nervous muscular tension was measured at the tips of the index and middle fingers of the left-hand which rested upon a large button connected with a hidden delicate instrument. This

automatically recorded the pressure unconsciously exerted by the fingers. When a glaring light-source was turned on, all the various subjects unconsciously exerted pressure upon the button. An extensive investigation proved conclusively that human seeing-machines exhibited nervous muscular tension from the shock of ordinary glare.

The ultimate objective was to measure, if possible, the nervous muscular tension developed by common visual tasks under various conditions of seeing. The variable chosen was intensity of illumination and the first task was the common one of reading. A book of moderately large type and dull paper, representing excellent typography, was chosen. The intensities of illumination varied from one footcandle (equivalent to the quantity of light one foot from an ordinary candle) to 100 footcandles. It will be recalled that outdoors in the summertime the intensity of illumination in the shade of a tree is about 1000 footcandles and that commonly indoors the intensity is only a few footcandles. Furthermore, millions of persons read daily under intensities of less than one footcandle.

A group of persons took part in this investigation during a period of many months. The subject read for a 30-minute period in each individual test of a carefully planned schedule. The subject was seated at a table containing an inclined rack

for holding the book, the entire set-up being determined by a study of comfortable postures. Each individual was instructed to read naturally and steadily, with the idea of serious recreation and not of speed. In other words, the research was conducted under normal rather than under forced or unnatural conditions. The brightnesses in the visual field were as suitable esthetically and visually as experience could produce. No preventable glare existed. The light came to the book chiefly from sources outside the visual field and actually located overhead and slightly to the rear. The only variable was intensity of illumination or footcandles.

The subject rested two fingers of the left hand naturally and comfortably upon a large flat knob of the concealed key. The fingers were to rest upon the key throughout the 30-minute period and were to press the knob down at the completion of each page. The reason given for this was that a record of pages was being kept so that the real reason was concealed. Sixteen subjects, male and female adults with average vision, continued this series of tests under the controlled and approved conditions of psychological research. Nearly a half million measurements of nervous muscular tension unconsciously exerted upon the key were automatically recorded so that the probable error of the summarized results was negligible.

Each subject showed a large decrease in nervous muscular tension as the intensity of illumination increased from one to 100 footcandles. The latter was the highest intensity investigated, because this is far above prevailing levels of illumination in the artificial world. There was impressive evidence that this tension would continue to decrease if the level of illumination were increased to 1000 footcandles. Without reservation, this is the most outstanding research in the invasion of the relatively unexplored and highly important realm of psycho-physiological effects of seeing. It shows conclusively the value of better seeing conditions in decreasing the cost of seeing to human beings and particularly the waste in useless internal work.

Incidentally, it is interesting to note that the rate of reading continued to increase with increase in the intensity of illumination, even though the subjects were asked to read normally as they would at home and that this was not a speed test in any sense. The conclusion is that as the task became easier they unconsciously read faster.

From this extensive research we have positive proof from dependable quantitative measurements that a visual task may be performed more and more easily as the seeing conditions are improved far above the threshold conditions or those under which the task can barely be per-

formed. The significance of such data is far-reaching, for it indicates that human resources can be conserved by improving any seeing factor. Considering the low level of seeing conditions and what civilization has imposed in unnatural and prolonged visual tasks, the possibility of reducing fatigue and nervous muscular tension appears very great.

It should be noted that this first quantitative measurement of this prevalent and important result of seeing was obtained with a very common task, by no means as severe as many, in the quiet restful surroundings of a laboratory with all conditions constant and probably close to ideal, excepting quantity and, perhaps, quality of light. One readily concludes that the opportunities of conserving human resources by improving seeing would be greater under the conditions of the work-world with its many distractions, demands upon other senses, severe tasks and generally sub-natural conditions.

### OTHER BENEFITS OF BETTER SEEING

Knowledge of the total and ultimate effects of visual effort, or of the entire activity of seeing, is by no means complete. Many deleterious effects of abuses of eyes and of the human seeing-machine are known. Even the total and ultimate penalties upon efficiency, health and general welfare,

resulting from the effects which have been isolated, can only be conjectured. It is known that certain disorders disappear when the abuses are corrected. Considering that the viewpoint of seeing has only recently been extended beyond the eyes to include seeing and the human seeing-machine, it is likely that other effects of poor seeing have remained hidden. Certainly nervous muscular tension, which is a very important effect of human activity, has not been definitely related to seeing until recently. Other work now in progress shows that seeing affects the human being very deeply and extensively.

It is known that eyes are permanently affected by abuse. Defects of refraction, particularly nearsightedness, have long been attributed largely to misuse of the eyes by having the visual task too close to them and by inadequate intensities of illumination, which encourage this bad practice. Fortunately, the science of optometry, the compensation of refractive defects by means of lenses, is well developed. As a consequence, oculists and optometrists serve admirably in correcting these effects of abuses. But they, in common with other progressive persons, know that this is primarily an age of prevention.

Even the refractive defects and other abnormalities of eyes induced by abuses are not necessarily permanent. When we become ill, Nature does

her part if we do ours toward getting well. Eyes have various recuperative powers, at least to some degree. Reducing their abuse by improving seeing conditions is always helpful and there are many cases on record where great improvement has resulted from this procedure. In fact, without correction of the abuse, the disorder usually becomes progressively worse. Poor lighting is the most important and universal cause of eye-strain often leading to progressive defects and disorders.

In studies of workers' eyes before and after improvements in seeing have been made, as, for example, increasing the intensity of illumination, improvements in the inherent powers of the eyes have been discovered. Statistics of this sort are rare, even though they are more important than those pertaining to the increase in defectiveness of eyes subjected year after year to unimproved conditions. The former deal with prevention and, therefore, are ultimately more important to civilized progress than the records of defects of continual indifference and abuse. There is hope and promise in the former; but in the latter there is little more than indictment for neglect and ignorance.

It is difficult to appraise the value of prevention of defects and disorders of the eyes and still more difficult to evaluate the conservation of other

human resources. Attempts have been made to do so in various ways, including monetary terms. An obvious partial appraisal of this sort mounts to staggering annual figures, even in a topsy-turvy system of human economics which often values the loss of life less than the loss of limbs. At any rate, eyesight is most highly evaluated among the parts of human machines.

As we expand our viewpoint from eyes into seeing and, in addition to physiological factors, attempt to include the beneficence of psychological effects, the difficulties involved in the entire appraisal increase still further. Who can completely evaluate results of good seeing conditions, such as greater stimulation, better impression, improved attitude, and increased confidence, concentration, and enthusiasm? These are natural effects upon the *human* part of the seeing-machine. And who would say that such results are not desirable in workers, profitable to employers, and delightful in associates in home, office and factory? They inevitably spring from better seeing conditions and they are nourished by seeing better conditions.

## Chapter III

# THE SCIENCE OF SEEING

Little is known about anything until it has been subjected to measurements. Without quantitative values established by more or less accurate measurements, knowledge of anything remains vague and uncertain. Test the truth of this statement upon the most commonplace things and then try to do so on economic and sociological factors. The muddle of the economic and sociological realm is ultimately traceable to a lack of accurate knowledge. The physicist can predict, within the limits of available knowledge, what will happen when certain physical forces act upon a given object. Likewise, the chemist predicts from organized and accurate records the result of adding this compound to that. These prophecies are certain of fulfillment within the limits of the accuracy of knowledge or experience.

Knowledge progresses not only in proportion to the quantity, but also to the quality of knowledge. For example, the great Isaac Newton, who first discovered or stated certain fundamental laws of gravitation, was correct within the limits of the accuracy of knowledge available at the

Each group of three threads consists of a white, a gray and a black thread. The visibility of each thread depends not only on light from the lamp but also on the relative brightness of its background. The brightness of the background depends not only upon the intensity of the illumination but also upon the reflection-factor. The science of seeing reveals the relationships of important fundamental factors.

time. Modern science is not only concerned with measurements, but is continually striving to increase their accuracy. Eventually, more precise measurements indicated that Newton's laws were not quite correct. Eventually, Albert Einstein refined these statements further to suit the latest refinements of measurements. Any science is an array of facts, tested and testable; and, therefore, incontestable within the limits of accuracy of the measurements which established them.

Sciences must develop, as a matter of practical expediency, from the physical into the physiological and psychological realms. Measurements are expressed in terms of the physical world into facts and laws, because that is the ultimate and universal basis upon which everything, including the universe, rests. Mathematics has been developed as the language of science. Owing to this necessary order in the development of the major sciences, the science of psychology is barely beginning to evolve. Human beings cannot understand themselves fully until the sciences involved have been fully developed. Therefore, we find ourselves with incomplete knowledge of important phases of the human beings, even though physical science has already gone far toward fathoming the mysteries of atoms and stars.

Man, the most important object to human

beings, is far less understood than stars at inconceivable distances or invisible atoms of inconceivable minuteness. And, until adequate knowledge of the human being is available, the sciences involving groups of them must remain inadequate. Therefore, the muddle of sociological factors continues. But modern science is not discouraged by the magnitude and complexity of its task. It forgets these in the enthusiasm of its immediate truth-getting activities. No science can be built in a day and it is not developed by those overawed by the magnitude of the entire task. Activity and courage are establishing facts by measurements and are correlating them with other facts which often seem unrelated. Any science is more than a record of incontestable facts; it is an organization of them into correlations. The science of seeing is acquiring many new facts; but of greatest importance is the correlation of the waste of human resources with the severe requirements of seeing imposed by civilization.

### THE EVENTS IN SEEING

Understanding is based upon measurements, but before these can be made it is essential to determine what is to be measured. The train of events with which we are concerned takes place in a fraction of a second. In a narrow sense it begins at the object to be seen and ends with

recognition of the object. As far as human beings are concerned, this train of events is internally beyond their control. But many external factors at the beginning of this train affect the visibility of the object and the ease of seeing; therefore, they affect the products beyond the end of the train.

Notwithstanding the lack of control over the complex system of events between the physical object and the mental impression, control of external physical factors which influence the ease and certainty of seeing also indirectly creates a high degree of control over the results upon the efficiency, behavior and welfare of the human being involved. In our complex world of industry, family and society, the relationship of this individual to others extends some degree of influence upon their welfare. Proof of this is evident everywhere, due to poor seeing conditions. The child's eyes rendered defective in school and home means economic loss to others. The pilots of trains and airplanes have the safety of others at stake. The production of the worker is depended upon by family and state. Many share the handicaps of the individual.

The train of events which takes place in a fraction of a second is not completely understood. Certain parts of it are still conjectural, but this is not of major consequence in this practical discus-

sion of seeing. Our primary interest lies in the controllable factors outside this internal train; but these can be understood better by knowing something of all the events of visual response. A brief summary of successive events may be stated as follows:

1. The physical object is the beginning of the train of events. Ease and certainty of seeing depend upon many controllable factors, such as size, form, brightness, color and contrast.

2. The stimulus is the light which comes from the object to the eyes. Actually, we do not see the object, but its form and pattern as expressed in brightness and color. Geometrically, the stimulus is a stream of light or radiant energy of definite cross-section.

3. The sense-organ process includes the optical and the photo-chemical processes. The image of the object is first focussed upon the sensitive retina by the optical parts. Thus the pattern of the cross-section of the stream of energy is altered in size, but not in form and detail, by normal eyes. The physical light or radiant energy is changed at the retina into another form of energy.

4. The receptor process is that which converts the light or radiant energy into something which stimulates the nerve-endings. The optic nerve may be considered a bundle of many nerves, the ends of the latter spreading out over the rear wall

of the eye to form the retina. Enough of these nerve-endings must be available so that enough parts of the pattern of the retinal image are sent to the brain to produce a sufficiently coherent picture. The process which takes place in the retina apparently is photo-chemical.

5. The socalled afferent nerve-stimulation is the process by which the effects in the receptors or nerve-endings of the retina are transformed into a nerve-current. This is the messenger and is easily thought of as an electric current whose cross-section retains the pattern of the image of the object.

6. A complex and little understood conduction of nerve-activity takes place through the retina and optic nerve to the brain-centers. Speculation combined with scientific knowledge readily divides this portion of the train of events into several processes which need not be presented in this brief glimpse.

7. The final stage is the perception or recognition of the object out in space. Although this is the end of the train of events involved in visual response, it is just the beginning of human interest. This stage is followed by mental and physical reactions. Something is done with the knowledge gained, but this final realm of human efficiency and welfare has been generally neglected in scientific studies and practical considerations.

As already stated, control exercised over the

external factors *before* the beginning of this chain results, in effect, in control over the results *after* the end of the train of visual response. The science of vision, expanded by knowledge of the external physical factors and resultant psycho-physiological effects, becomes a science of seeing.

### SEEING IS A TRIPLE COMPLEXITY

The science of seeing must deal with three major complexities which are interdependent and to some extent intermingled. However, it aids in understanding and unraveling the factors, processes and effects of seeing, to consider them separately. Briefly, they may be described as follows:

1. The external world of physical factors.
2. The eyes, visual sense, and successive events of visual response.
3. The psycho-physiological effects pertaining to human behavior, efficiency, welfare and happiness.

These are briefly analyzed in the paragraphs which follow. In other chapters, scientific facts and practical applications are presented.

### THE EXTERNAL PHYSICAL FACTORS

These are in the external physical world. They include brightness and color, which are in reality

sensations, described by physical causes and commonly considered as physical factors. This is the realm of visibility of objects consisting of many factors and combinations of them. The major factors are object, background, light and lighting. The object generally has size, form, color and brightness. The background may have these characteristics, although, in the simplest cases, its size and form may not be important. Contrast may be due to a difference in brightness or color, or both, between the object and its immediate background or surroundings. Light produces brightness and color. Lighting involves the distribution of light, which includes the direction and diffusion of light and the relative location and extent of the source or sources of light. The lighting produces highlights and shadows which play very important rôles in the perception and the recognition of objects.

Surroundings influence visibility generally by distracting attention and tending to conceal the existence of an object. Camouflage during the World War dealt with visibility. Sometimes it aimed to conceal objects by covering them with something, generally painted colors and patterns which blended inconspicuously into the surroundings. Sometimes it aimed to conceal by a confusion pattern. It is not surprising that a bird

with dull brown plumage and subdued pattern is inconspicuous in the woods. But the low visibility of striking patterns is generally astonishing. A zebra in a circus is very conspicuous; but, amid the variety of pattern of its natural habitat, it is of low visibility. This is true of the gaudy colored and patterned woodcock, male mallard duck and countless living things.

All these factors must be subjected to measurement in the evolution of a science of seeing. Many influences and relationships of important factors are now known. Of course, in such a complexity as this it is impossible to express all the factors in exact terms. For example, it is difficult to describe colors, highlights and shadows completely. With knowledge of the major factors established by measurements one may combine the observations and experiences of every-day seeing so that most conditions of seeing can be considerably improved.

Superposed upon all the complexity of external physical factors is the element of time. Even though the entire train of events of visual response takes place in a fraction of a second, it takes time to see. Besides, seeing in its practical sense usually is followed by an act on the part of the human seeing-machine. The reaction-time of the human being thus becomes a practical factor in the entire activity of seeing.

### THE VISUAL SENSE

This includes the eyes and the entire sensory process to the brain-centers. This is the visual tool in its broad sense, but for the most part it is not controllable. This is the part of seeing which has usually been mistaken for seeing. Knowledge of this part of seeing is the science of vision and it is relatively well developed. Understanding of the functions and limitations of the visual sense is necessary to an understanding of the practical possibilities of seeing. However, we are interested chiefly in factors which can be controlled and most of those of the visual sense cannot be.

Refractive errors, which are so common, can be corrected. Therefore, eye-glasses supplied by the skilled oculist and optometrist are important controllable factors which really belong to the external physical world. Many persons need corrective glasses and the percentage increases with age. This is one of the penalties of civilization. Fortunately, knowledge and skill are available for making and fitting these corrective devices which "sharpen" the visual tools so that they are ready to do their best in the activity of the human seeing-machine. Later, it will be shown how prevalent refractive errors are, how they vary with age and occupation, how they handicap seeing and how they decrease the production of useful work.

The pupil of the eye and the adaptation of the retina are the only internal factors of the visual sense which are controllable by external means. Adaptation is affected by the brightnesses in the visual field. Looking alternately from brighter to darker areas reduces the efficiency of vision. The pupil is subject to a slight, but important, control. However, it is more important as the one part of the entire visible portion of the visual sense that is visibly affected by external factors. It also seems to be influenced by certain internal results of seeing. Records of its size under various conditions of external factors, such as brightness, and of the internal factors, such as fatigue, promise to aid in understanding seeing and the results of this activity upon human beings.

The science of seeing deals with the eyes or, more broadly, the visual sense as a physico-physiological instrument and process of various parts and functions. It is particularly interested in the abilities, limitations and mutual influences of the parts and functions upon the efficiency and welfare of this mechanism and of the human seeing-machine.

### INTERNAL PSYCHO-PHYSIOLOGICAL EFFECTS

The boundary lines of this realm are not very definite. They may include the final practical results upon human efficiency and welfare. They

could encompass the mental processes in the train of events of visual response. However, these are so logically a part of the visual sense that they are automatically included in the foregoing section. It simplifies the division of the triple-complexity of seeing to include in the third part only the physiological and psychological results of seeing. These are the costs to the human seeing-machine of doing visual work.

Measurements in this realm are very difficult to make for several reasons. The effects are obscurely intermingled with each other and with the entire mental and bodily processes. The boundary line between the physiological and psychological may be fairly clear in modern science, but not in many of the effects of seeing. The effects must be measured for the most part indirectly by objective methods. Technique and methods must be developed, because the sciences involved are in early stages of development. Interpretations of the results are sometimes difficult because the measurements are so easily prejudiced by improper technique and at best may include simultaneous results of more than one effect.

In the study of psycho-physiological effects of seeing, the human being is the experimental material and it is by no means stable or unchanging. The experimental technique itself may

introduce changes in the response of the human subject. In general, the subject must be unaware of the purpose of the investigation, insofar as it is possible to conceal it. A direct question in regard to comfort, fatigue or other effect may emphasize something to the subject which immediately makes him unnormal. Results upon normal human beings unprejudiced by conditions and state of mind are desired, but are often difficult to obtain.

Notwithstanding the difficulties involved in making measurements in this realm and the recency of the invasion, promising progress has been made. Excellent quantitative data pertaining to nervous muscular tension have recently been very encouraging. This is a known factor in seeing which conspicuously drains human resources in many activities.

Fatigue of certain eye-muscles is indicated by their power to maintain the muscle-balance required for convergence of the eyes. Recent measurements of the pupil size encourage the prediction that it may become a reliable indicator of eye-fatigue and even general bodily fatigue. The latter consists of fatigue due to seeing and all other activities engaged in. These can scarcely be separated in practice. However, they can be practically separated by studying purely visual tasks under ideal conditions in every respect

excepting seeing. If seeing is the only voluntary activity involved and its conditions can be varied, it can be demonstrated that general bodily fatigue results from seeing and comparisons of the fatigue induced by different seeing conditions can be made. In such experiments, fatigue need not be measured directly or absolutely, for any method which satisfactorily indicates fatigue would yield valuable results. Certainly, this is of personal, social and economic importance.

Discomfort can be studied for various conditions of seeing. This effect can be established by forcing oneself to do serious visual work at the threshold of visibility under conditions which cause no discomfort when the task is temporarily suspended. This is a condition often experienced. For example, one can converse with comfort under conditions which are definitely annoying for serious visual work, such as reading. Qualitative results can be obtained in many ways. It is also possible to establish a scale of discomfort beginning with pleasant and passing successively to disagreeable, irritating and painful. It is difficult to transmit this scale to other persons, but it can be done with sufficient certainty to yield results which are valuable.

The degree of stimulation of agreeable seeing conditions, lighting effects or visible environment manifests itself upon the amount of work done

in a carefully controlled research. Even some measure of this can be obtained from the rate of performance of a task done solely by touch while the visual sense is stimulated in various ways. Relaxation and restfulness due to certain surroundings are a matter of common observation. The influence of seeing conditions upon the rate and uniformity of tapping a key which makes and breaks an electrical circuit has been used in such studies. Even the heart-beats and respiration are possible indicators. Nervous muscular tension should result in increased consumption of oxygen and, therefore, conditions which cause it might also affect the rate of pulse and respiration appreciably.

The effect of distractions can be studied by their effects upon reaction-time, speed of seeing, and rate of production of useful work. They should be factors in the production of nervous muscular tension and fatigue. Apparently, much of the annoyance of a glaring light-source in the visual field is due to the constant effort one must make to overcome the distraction. Attentiveness to a task or ability to concentrate is measurable in terms of amount of work done and of the kind and number of errors made. Even attitude exhibits its effects in quantity and quality of work done. Enthusiasm, contentment and happiness leave their imprints in many ways and, therefore, can be subjected to measurement.

These are examples of the kind of effects which must be measured in completing the science of seeing. Some valuable records can be obtained from large groups of persons by carefully controlled experiments involving the judgments of individuals in regard to preference, satisfactoriness, discomfort, etc. However, the opinion of an individual based upon his own casual and untrained observation is generally valueless. In seeing, this can be proved in many ways. Therefore, in researches involving the judgment of the subjects, the technique must be such that the answer is easy to give and that the subjects do not know or, worse still, do not think they know the correct answer.

## SEEING THE THIRD DIMENSION

The constant intrusion of psychological factors in seeing is perhaps the best evidence of its extreme complexity. We make many allowances automatically in the perception of objects. Some of these we learned to do before thinking became a conscious act. Most persons do not know that they had to learn to make allowances and interpretations, for these are now so hidden in the complex automatic activity of seeing. It is this very commonplaceness which contributes toward abuses and to the suffering of severe penalties unknowingly.

Seeing things out in space where they are,

instead of on the retina where the image is, is one of the outstanding psychological features of seeing. We have learned to do this. Also, we have learned to do many other things automatically. A few glimpses of these in connection with binocular vision further emphasize the complex entanglement of the physical, physiological and psychological factors and processes.

As we go up the scale of vertebrate animals and note the position of their eyes, it is seen that this changes gradually from the sides to the front of the head. The optical axes of the two eyes change in inclination from 180 degrees to parallel. This means that monocular vision changes to binocular vision. One only needs to note how a chicken or bird cocks its head to look intently at something to see the dominance of monocular vision in this case. Apparently, along with this change from monocular to binocular vision, there is also an increase in the fineness of the bacillary layer of the retina from the margins toward the center. This results in an increasing accuracy in the perception of form and, eventually, in a highly organized central spot or fovea possessed by human beings and the higher monkeys. Proceeding up the scale we also find an increasing ability to converge the optic axes on a near point so that the images of the point on each retina, respectively, may coincide with the central spots of each retina. Such changes

are closely associated with each other and, of still greater importance, with the development of the higher faculties of the mind. In fact, binocular vision requires much of the mind.

Binocular vision in man, and in the higher animals, is the last result of the gradual improvement of the most refined sense-organ, adapting it to meet the requirements of highly complex organisms. The normal positions of the optical axes of the eyes is approximately parallel. They can be converged automatically and without conscious effort upon points beyond a few inches from the eyes. Within this range conscious effort even to the point of pain is required. The optical axes can also be diverged. In fact, with practice it is possible to diverge the axes sufficiently to look at a point so far beyond infinity that it is near the back of the head. Of course, we do not see the point!

The movements of the eyes are rather complex. Here, we are not interested in them as such, but in what they convey to us. Through experience begun in early infancy, we unconsciously evaluate the muscular stresses, efforts, and movements and, thereby, through seeing, interpret much pertaining to the size, shape and distance of objects in the external world out of reach. This is another great achievement added to the appraisal by monocular vision.

Stereoscopic vision contributes much toward

the perception of the third dimension or depth. Each eye sees a slightly different scene or pattern. Automatic interpretations of these contribute to the knowledge which monocular vision would provide.

Thus it is seen that the visual sense developed to use light, the speeding messenger to which air is transparent, as the connecting link between objects and human beings who see the objects at a distance. As if this were not a sufficiently marvelous achievement, binocular vision was developed to add refinements by interpreting muscular movements and stereoscopic images. It might be added that the retinal images are upside down and we have learned to see the objects right side up. There are many interesting psychological factors and processes which are the results of experience and are automatically playing important parts in the entire activity of seeing.

The perception of the third dimension of space and of objects, and other aspects of the external world, is achieved principally by noting the following:

1. Extent
2. Perspective
3. Cast shadows
4. Stereoscopic vision
5. Elevation of objects

6. Variation of light and shade on objects
7. Interference of near objects with those more distant
8. Muscular effort attending accommodation of the eye
9. Variation of the visor angle in proportion to distance
10. Muscular effort attending convergence of the axes of the eyes
11. Clearness of objects as affected by atmospheric haze

A great deal is known about some of these factors, but much remains to be done in coördinating them into the science of seeing. They are mentioned here as another important part of this sketch of seeing. Without understanding these factors and at least without having them in mind, the applied science of seeing cannot progress very far. Among these are some controllable factors of great importance.

### SEEING IS DECEIVING

An intimate study of measurable and unmeasurable factors, and the controllable and uncontrollable ones, eventually leads into a maze of deceptions. The familiar epigram—seeing is believing—may be paraphrased as in the foregoing title to describe the realm of visual illusions. There are as many deceptions as there are visual

situations, for it may be said that we never see anything exactly as it is appraised by physical instruments. For the most part the illusions are of minor consequence and of no practical significance. Either our appraisal does not depart far from the physical reality or we have learned to compensate for the vagaries of our senses. However, many illusions are important; and knowledge of the many phases of illusions is necessary if one is to understand seeing and to analyze accurately any given visual situation. This realm of unreality is a part of the science of seeing and even illusions can be subjected to measurement. It is possible to measure the degree of physical alteration necessary to make a situation appear to us as it was physically before the correction.

We do not see things exactly as they are or as they are related to each other. If we look at a line, form, mass or color, it is always influenced by something else in the visual field. We cannot isolate anything visually. The background may be plain and of infinite extent so it does not have form; but its brightness influences the appearance of the object. Its brightness makes a darker line or form appear darker. If the object is seen amid darkness, the blackness makes the object appear brighter than it is. Only when the brightness of the background is equal to that of

the object does it cease to be an influence—and then the object cannot be seen because there is no contrast. The same is true of color and any other factors, such as the relation of lines, masses and forms. And motion introduces a vast variety of unrealities, because it takes time for visual sensations to rise and to fall.

In most cases the intellect does not correctly interpret the deliverances of the visual sense; in others the optical system of the eyes or a part of the visual process is directly responsible. Only a part of what is perceived comes from the object; the remainder always comes from within us. Our past experiences, associations, desires, demands, imaginings and other more or less obscure influences, prejudice our senses and our minds and create illusions. Some are traceable to, and are expressible in terms of, physical laws or analogies to these. Many are errors of judgment based upon what is common experience which is not always dependable. Others are much more complex. Most of them involve an understanding of psychological effects.

A science of seeing must include these errors of sense and intellect which are visible on every hand. From the viewpoint of accurately appraising the physical world, they are very important. Many controversies have been based upon seeing something differing from the reality. Doubtless,

many accidents have been due to them. Many important erroneous conclusions arise in lighting and in seeing due to lack of appreciation of the existence and prevalence of illusions. In analyzing any situation, experience or alleged fact in seeing, it is always well to keep in mind the possibility of an illusion. Many analyses and correct explanations lead one into this complex realm.

There is an important phase of illusions where impression is of primary importance. Their widespread existence and their forcefulness make visual perception the final judge in various arts, such as decoration, painting, architecture, landscaping and lighting. Any detail of a painting may well be an illusion if it serves its purpose. Indeed, a painting is an illusion itself. Where impression is important and satisfactory, there should be no quarrel with the reality, whatever it may be.

### WE ARE NOT DEPENDABLE SEEING-METERS

From these glimpses of various realms of the science of seeing it is obvious that seeing is a supercomplexity. Certainly, one must conclude that there is need for a science of seeing and that no science is more important to human beings. Perhaps these excursions into highways and byways of the subject may aid in eradicating the general idea that a human being is a dependable

seeing-meter. One does not weigh a roast of beef in his hands; he depends upon the scales in the market-place. One uses a thermometer as a guide to the temperature of the room. Seeing is by far more complex than experiencing weight and temperature. Perhaps good excuses for attempting to appraise seeing conditions are found in the fact that no other seeing-meters are available. Furthermore, because we can see under very adverse conditions, without receiving prompt and direct warnings, it is natural that human beings have not become aware of the costs of poor seeing conditions.

One of the major points which the science of seeing has proved is that human beings are not dependable seeing-meters. Vision is elastic. The focus of the eyes and of the attention varies from moment to moment. The effects of seeing take time to accumulate. They manifest themselves indirectly. They are well hidden and are difficult to measure even in the laboratory. For these reasons it is difficult to demonstrate the important factors and effects of seeing.

With increasing knowledge of seeing, certain demonstrations can be developed; but, of course, no physical instrument can ever become a human seeing-machine. It lacks the very human elements which concern us. It cannot experience psycho-physiological effects. Some relationships of external physical factors can be demonstrated,

but the vagaries of the human part of the seeing-machine make a quick appraisal valueless. Extensive statistical data must be obtained under controlled conditions of careful research in order to establish dependable facts. Some demonstrations can be made quickly near the limits of visibility, but this is a condition rarely of interest and importance. Even under the generally poor conditions of seeing in the artificial world, threshold visibility is rare. Optimum conditions must be determined by careful research and also correlations of these with threshold ones.

A science of seeing is important not only as a coordination of knowledge badly needed by human beings who are so dependent upon seeing, but also because they themselves are not dependable seeing-meters. At last this science is being evolved, but its contribution to humanity will be proportional to its general application in this half-seeing world. Extensive application is not only the job of the future seeing specialist, but is the responsibility of everyone.

### CONTROL OF SEEING CONDITIONS

The human seeing-machine is interested in

The visual task
The eyes and visual sense
Light and lighting

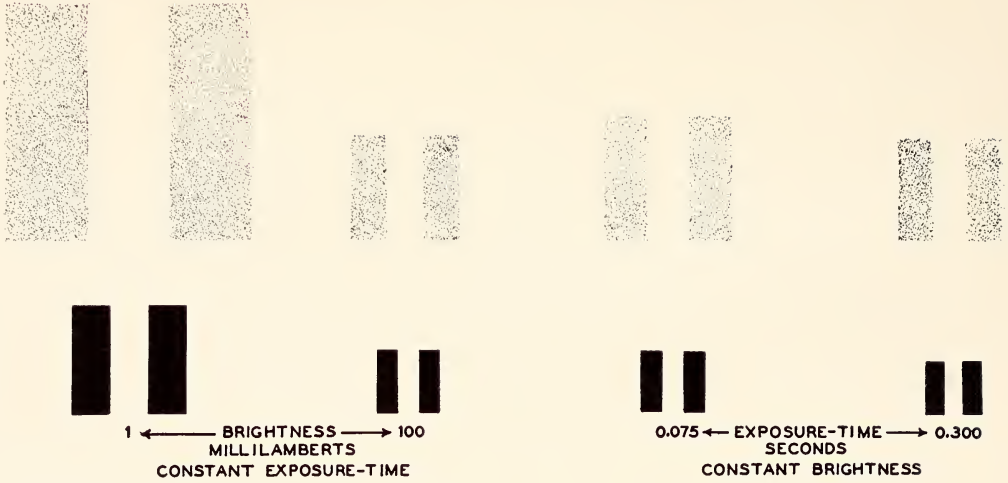
What can be done toward improving seeing conditions depends upon the controllability of the foregoing three factors. Some visual tasks are controllable by someone. For example, printers can use larger type. However, human seeing-machines must accept the visual tasks generally as they are. In other words, control over visual tasks is limited. After eyes have been corrected, if necessary, by proper glasses, no further control of them is possible. Light is as essential in seeing as eyes are and lighting is generally controllable by someone and, in most seeing, it is controllable by the person who has to do the seeing. In other words, there are few limitations imposed upon the control of light. This means that lighting is promoted from insignificance to a major rôle by the science of seeing. A seeing consciousness, when aroused, in turn arouses a lighting consciousness. They go hand in hand.

## Chapter IV

# VISIBILITY OF OBJECTS

Through improvements in the visibility of objects, the waste of human resources can be materially reduced. Eyesight, energy, life, health and other human resources are conserved in this way. Visibility is controllable beyond the threshold limitations of internal functions, for it depends upon many external factors associated with the object or visual task. In reading, for example, the type, ink, paper and printing are fixed as far as the reader is concerned, but they are controllable by the printer. Usually, the reader can exercise partial or complete control over such important factors as quantity and direction of light. The reader is often free to refuse to read books of fine print. So it is with most visual tasks, and no person possessing eyesight is entirely free of the responsibility of improving visibility. For many, the responsibility should become an impressive duty involving human welfare.

Visibility in even the simplest case is a complex combination of various factors. But when the most complex case is analyzed, it is seen that the factors themselves are simple. By unraveling




The upper objects are of low contrast; the lower ones are of high contrast. The contrasts (in the original) were 15 per cent and 97 per cent, respectively. They represent the relative sizes necessary if the object is to be barely distinguished as two bars for the conditions indicated. In the group of four objects at the left the effect of brightness of the white background is shown as produced by approximately one and 100 footcandles, respectively. In the right-hand group of four is shown the effect of time available for seeing.

this complexity and by studying the contributions and limitations of the factors which influence visibility, an important part of the science of seeing is constructed. Much basic knowledge of visibility is now available and this has many practical applications in everyday seeing from which everyone would derive benefit. Visibility can only be measured at the limiting or threshold conditions and is usually determined under ideal conditions of the laboratory. Actual seeing is usually performed amid distractions which can be offset to some extent by adequate factors of safety.

Neither casual nor exact appraisals of visibility provide direct knowledge pertaining to ease of seeing or to the ultimate welfare of human beings engaged for long periods in serious visual tasks. However, scientific research has established an important correlation between visibility and nervous muscular tension developed in the human seeing-machine. Ease and certainty of seeing are closely related to visibility.

When visibility is high, the task is easier upon the human seeing-machine than when it is low. But it should be borne in mind that time is necessary to drain human resources, to damage eyes, to become fatigued, to feel the effects of nervous muscular tension and to develop the more commonly recognized disorders, such as headache, dizziness and indigestion. High visi-

bility means greater certainty of seeing and aids in counteracting the effects of distractions. Increased certainty means better work and, in many cases, increased safety. Therefore, the very foundation of the welfare of human beings, as it is related to seeing, rests upon visibility and upon knowledge of the influences, limitations and control of the various factors.

Many of these factors are merely mentioned in this chapter, but the more important fundamental ones are discussed briefly. In other chapters these factors appear in the rôles which they play in typical visual tasks. Visibility must be unraveled as a part of the process of unraveling the greater complexity—seeing. We must take anything apart before we can understand it thoroughly. And knowledge of what the parts do makes it possible to extend their use. So it is with visibility. The parts, when understood, can be used to the best advantage in decreasing the severity of the numberless unnatural visual tasks which tax human beings and in increasing the certainty of seeing upon which human lives and limbs depend.

## FOUR FUNDAMENTAL FACTORS

From the viewpoint of visibility, objects vary from simplicity to extreme complexity. All objects are relatively simple when merely *perception* is involved. When they must be *recognized*, their

complexity becomes evident. In many cases, such as driving along a highway at night, one is usually more concerned with perceiving an object on the roadway than in recognizing it. Often safety is well served merely by perception. However, in most serious visual tasks recognition of critical details is necessary.

A series of familiar objects increasing in complexity is represented by a circular dot, the letter *O*, the letter *C*, a short word, and a long word. The critical details which must be seen, if simple objects are to be recognized, are usually obvious. In a short word, the important ones are those in the letters most difficult to recognize. That the individual letters of a word, which we may seemingly recognize as a whole, are important is proved by the conspicuousness of typographical errors. Recognition of long words and of sentences involves eye-movements and other factors which need not be considered for the present. However, when recognition is traced down to fundamental details, it is found that there are four factors of primary interest. They are,

*Size* of a simple object, or of the critical detail of a complex one, upon which recognition depends.

*Contrast* in brightness (or color) between an object and its background.

*Brightness* of the object or of its background.

*Time* available for recognizing the object.

Each of these factors can be studied by keeping the others constant. In everyday seeing they are interwoven. If an object is to be seen or any visual task is to be performed, each of these fundamental factors must be greater than a certain absolute threshold value, which is fixed by the limitations of the visual sense, of reaction-time and of the human seeing-machine as a whole. The actual threshold value is determined within certain limits by the values of the other factors. For example, the smallest object which can be recognized depends upon the other three factors. If the contrast is high, as in the case of a black thread on a white background, a lower brightness or a shorter exposure-time is required for perceiving the thread than when the contrast is low, as in the case of a black thread on a dark gray background. Brightness and time influence threshold size in the same manner. For example, smaller type can be read more easily on the porch in the daytime than indoors at night under the usually much lower intensities of illumination. Although very short periods of time are involved in recognition, it is obvious that an object of high brightness can be seen more quickly than one of low brightness.

All factors are dependent upon each other when their values are above those limits fixed by the inherent limitations of the human seeing-machine.

Even though these four factors are simple, their interdependence upon each other presents difficulties in discussing them. Four variables cannot be compared at the same time. Each factor must be considered with each of the others.

Color and spectral composition of light introduce such complexities into the discussion of the fundamental factors that it is best to treat them separately. Contrast in color is often of consequence; but contrast in brightness is more generally and fundamentally important. Color-vision is depended upon a great deal more than most persons are conscious of; but, excepting in special cases, color is generally a secondary influence superposed upon brightness. When the ultimate in visibility, ease of seeing and psychological effect is desired, color and spectral character must be considered.

### SIZE

Size of an object or of a critical detail is the most generally noticeable factor in visibility. For this reason it has been given a great deal of attention at the expense of other factors. In fact, it has held the center of the stage in researches pertaining to the visual sense, and other factors have been left in obscurity. Everyday experiences prove to anyone the importance of size in the visibility of objects or details. Fine print

is unreadable under many conditions commonly met. The eye of a needle may be undetectable under many conditions. One may be obliged to take the telephone directory to a window where more light renders the name and number legible. A needle is commonly turned this way and that until the tiny eye is outlined by a highlight or by a bright background. In many ways everyone unconsciously controls certain visibility factors temporarily for obviously critical visual tasks. But nearly everyone ignores the possibilities of permanent improvements in seeing conditions which would continuously pay dividends. The cost of most improvements is little or nothing besides the application of knowledge; and they are easy to make.

Size is the simplest fundamental factor in seeing, but even this has some complexity. It is of interest in two quite different ways. If we are interested in a single object, such as the period preceding this sentence, size refers to the critical dimensions, which in this case is the diameter of the dot. This is a very simple visual task and is not uncommon. However, visibility usually involves the resolution of details, that is, the visual separation of them. Seeing the letter *i* involves distinct separation of the dot, so that two separate mental images are the final result. Size in this case means the width of the white space separating

the two parts of the letter. Thus, the resolving power of the visual sense becomes important, as well as definition of the retinal image. In the simple case of a single object, definition, or accurate focusing of the image upon the retina, is all-important.

In order to understand the discrimination of size and the limitations of the visual sense, it is necessary to examine the retina. This consists of many endings of the individual nerves which form the optical nerve. The latter is, in effect, a cable. These many nerve-endings are very small and are arranged in haphazard array. In order that a dot, such as the preceding period, may be seen, its image must fall upon one or more of these tiny nerve-endings which are the receptors. The dot is seen, if enough light or radiant energy falls on a single receptor in the limiting case.

The resolution of two objects close together is more involved. With the point of a pencil make many dots close together in haphazard array over an area about the size of a dime. This represents the retinal receptors. Now let us suppose that we are trying to discriminate or resolve two parallel lines close together. They are seen as two lines, if enough different nerve-endings are adequately stimulated by the retinal image of each line. Draw a line on the dotted area, just

made with a pencil, as straight as possible, connecting successive dots. It will not be straight. Now draw another line as close to this as possible connecting other dots. It should be obvious that the two lines of the actual object must be separated by a dimension greater than the diameter of a single object, such as a period, for threshold or limiting visibility in the two cases. The image of a period need not be as large as a single retinal receptor. It merely needs to fall on one and, provided there is sufficient radiant energy to stimulate the receptor, this simple object becomes visible. Actually, as an optical instrument, the eye is not perfect enough to produce such a small image.

Actually two parallel lines must be separated by a distance about ten times as great as the diameter of a simple object, such as a period, for threshold visibility in the two cases.

From the viewpoint of seeing, size is not merely the physical dimension of an object or critical detail, as measured with fine calipers. Visual size involves distance as well. The visual size of any dimension or detail of a person is only one-tenth as large at a distance of 100 feet as at 10 feet. Everyone knows that the distance between the steel rails of a railroad track remains constant in physical size, but the visual size decreases exactly in proportion to the distance

from the eyes. When this distance is great enough the two rails seem to merge. Actually, this is the limit of resolution of the visual sense.

The visual size of the letters on this page is half as great at a distance of 28 inches as it is at the socalled normal reading distance of 14 inches. This explains the tendency to hold fine print closer to the eyes than large print. This also explains why, under poor conditions of seeing or low visibility due to inadequacy of light or of any other factor, the eyes are unconsciously brought closer to any visual task. The result is increased strain of the eye-muscles due to excessive convergence. Prolonged practice of this abuse accounts for much of the prevalent nearsightedness.

Owing to the diminishing elasticity of the eye-lens with age, farsightedness increases with age. Nearly everyone past middle age knows that the eyes cannot focus objects as close to them as they were able to do in earlier years. With advancing age farsightedness increases until, finally, the nearest point of focus becomes far out of reach of the arms. As age advances it may be necessary to hold a newspaper at arm's length in order to read it. From the viewpoint of visual size this fine print has become about half as large as it is at a distance of 14 inches. The best solution is correct glasses, which aid in focussing at a point closer to the eyes. Other factors, such as quan-

tity of light, are also helpful and even necessary as is shown elsewhere.

Visual size must be expressed in terms which take into account distance of the object from the eyes as well as the physical dimension of it or its critical details. This is readily done by expressing it in terms of the angle between two straight lines drawn from the extremities of the object or detail so as to intersect at the eye. This is a very small angle, as is seen if one visualizes the angle between two straight lines starting at the same point in the center of the pupil and ending, respectively, at the two ends of the space separating the dot from the remainder of the letter *i*. Angles are expressed in degrees, minutes and seconds, as in the case of latitude which is the angular distance north or south of the equator. The earth as a sphere has 90 degrees of latitude from the equator to the pole. Visual angles involved in visibility are so small they are conveniently expressed in minutes and seconds. There are 60 seconds in a minute, 60 minutes in a degree, 90 degrees in a right-angle, and 360 degrees around a point such as the center of a circle. Of course, the minutes and seconds have nothing to do with time.

In order to aid in comprehending this unit a dimension of 0.004 inch at a distance of 14 inches has a visual size of *one minute*. A dimension of 0.01 inch at a distance of 35 inches also is one

minute in visual size. When two parallel black lines on a white paper and separated by a white space of the foregoing width are viewed at the foregoing distances, respectively, they are at the limit of visibility, as two distinct lines, for average normal eyes. The best eyes can resolve them from these distances, respectively, if the physical separation of the two lines, or the size of the critical detail, is reduced to 40 seconds. The minimum visual size of a black dot on a white paper, which is just visible to average normal eyes or those fully corrected by glasses, is about five seconds. That is, the dot must have a minimum diameter of about 0.001 inch at a distance of 35 inches.

These threshold sizes are for objects of high contrast with their backgrounds and are determined under ideal laboratory conditions as to distractions. Furthermore, the objects are displayed in simple fields and not amid the usual surroundings which reduce visibility. Therefore, considerable allowance must be made by means of large factors of safety in size for the everyday conditions of seeing.

Excepting in the case of printed matter, there are few cases of visibility representing high contrast. The threshold or minimum size visible is considerably larger when the contrast is low, as in the case of printed matter on a dark gray

background or a black thread against dark cloth. Brightness level or intensity of illumination also affects the limiting size, which is barely visible. These are discussed in connection with those factors.

It may be interesting to know something of the visual sizes of familiar objects at the common distance of 14 inches. Visual tasks should not be performed for long periods with the eyes closer than this. The visual size of the space between the dot and the remainder of the letter *i* is about 1.7 minutes for 6-point type at a distance of 14 inches. It is seen that this is approaching the threshold of visibility for normal eyes. Furthermore, various complexities enter reading under everyday conditions so that one can scarcely conclude that 1.7 minutes represent an adequate factor of safety for normal eyes or those properly corrected by glasses. Certainly, it is far out of the range of desirability for subnormal eyes and ordinary lighting conditions.

The visual size of the same critical detail for 8-point type at 14 inches is about 3.9 minutes; for 10-point about 4.9 minutes; and for 12-point about 6.4 minutes.

Newspapers are commonly printed with 8-point type. Leads for murder stories and matters of similar importance draw larger type for a paragraph or two; but serious material, such as scientific knowledge and achievements, often are

set in 6-point type. In fact, a great deal of the body of a newspaper is in 6-point type. Combining with this small type the necessarily low grade thin paper and the effects of hasty printing, the newspaper is an example of a severe visual task with no appreciable factor of safety above threshold conditions. This book is printed in 12-point type.

Books are sometimes printed in 12-point or even larger type. Considerable advances have been made in this respect and now one might well decline to abuse the eyes and the human seeing-machine with a book, of finer print than 10-point, which is to be read for long periods. Books also are generally examples of good typography, paper and printing. Those who have a mania for legislating alleged welfare might well turn their efforts to printing, lighting and other controllable factors as a really commendable and justifiable effort to reduce waste of human resources.

For practical reasons the minimum might be 8-point for newspapers and 10-point for books, although a size larger in each case would be better. Children's books are now being printed in satisfactorily large type, although inadequate light, improper lighting and position of the page are still taking a large toll in damaged eyes. Legibility of print is also affected by the style or character of the type-face.

The width of the eyes of needles in the common

package of assorted sizes varies from 2.5 to 4.6 minutes visual angle at 14 inches. The distance between two adjacent rulings on a steel scale representing one hundredth of an inch is about one minute at 14 inches. The spaces between the dots of the half-tone pattern of a 120-screen is about 1.7 minutes. For a 65-screen it is about 3.5 minutes at the so-called normal distance of 14 inches from the eyes.

### CONTRAST

It is difficult to say what is the most valuable possession of a human being, for it is difficult to choose between possessions so different. The same is true when we consider factors which influence visibility. However, just as we rank eyesight high, and even foremost in the one case, so must contrast be appraised in the other case. Not until systematic research recently began the development of a science of seeing was the influence of contrast accurately known or even its importance adequately appreciated. Where it is controllable, it is the most generally influential factor in increasing visibility, but often its value is approximately fixed, at least within a certain practical limit.

We may arbitrarily express the contrast between a perfectly black object and a perfectly white background as 100 per cent. This is an arbitrary,

but very practicable, definition. Some difficulties are encountered in expressing contrast between self-luminous or translucent objects in the midst of dark or opaque backgrounds, but these are special cases. Most visual tasks involve reflecting media. Reading for example, involves approximately black print on approximately white paper. The black ink always reflects some light and the white paper never reflects all the light. As a consequence, the best book typography presents a contrast of 97 per cent; a newspaper perhaps 85 per cent; and an average telephone directory about 80 per cent.

Let us take the case of a telephone directory with its cheap, thin paper and determine the relative visibility of certain critical details compared with their visibility if printed on good book paper. Also, we shall see how this lower visibility can be compensated by increasing the intensity of illumination. The effect of the lower contrast can be overcome by increasing the brightness of the page. This can be done by more light, that is, by increasing the intensity of illumination. From knowledge pertaining to the influence of contrast upon visibility, it is known that the page of the telephone directory must be about twice as bright as the page of good book paper in order that the same critical details of names and numbers may have the same visibility. But the

paper of the directory reflects only 57 per cent of the incident light, while the book paper reflects about 80 per cent. To compensate for this so-called lower reflection-factor of the poorer paper, additional light is needed. The final result is that the intensity of illumination should be about three times as great on a page of the average telephone directory as on a page of white book paper, if the details are to be equally visible. This shows how quantity of light overcomes the two handicaps of lower contrast and lower reflection-factor.

The minimum contrast in brightness, which is barely visible under ideal conditions, is about one per cent. This is greatly influenced by the level of brightness and by the time available for recognizing the object. Under ordinary conditions a contrast of one per cent could not be seen. High contrast means high visibility, if other factors are adequate. This is why approximately white paper and black ink are generally best for reading.

Refinements are possible in the use of slight tints of color by taking into account a certain optical defect of the eye and giving consideration to esthetic aspects. Often signs and other objects must not only be highly visible, but they must attract the attention. Here color plays a part often determined by the surroundings. In

general, black letters on a yellow-orange background have a lesser contrast than on a white background; but the attention-value of color may more than overcome the lowered visibility due to the decrease in contrast. However, the consideration of color is eliminated from the present discussion.

It has been seen that the visual size of the interval between two details of an object must be about one minute, or greater, if this critical detail is to be barely visible under ideal conditions. The latter include high contrast, such as black on white. When the same details are seen against a fairly dark gray background so that the contrast is reduced to 15 per cent, the minimum size is now about 2.3 minutes. Thus it is seen that the threshold or minimum size visible is very greatly influenced by contrast. This is why it was stated at the outset of the present discussion that contrast is the most generally important factor in visibility. Attention to it yields good dividends in increased visibility and, therefore, in greater ease of seeing.

It is interesting to consider briefly the contrasts common in visual tasks. Reading involves high contrasts very generally; and it is a common visual task. Even scientific research usually dealt with high-contrast test-objects made by placing black characters on a white background. Consequently,

most ideas pertaining to vision were thoughtlessly based upon high contrast. With the exception of reading and some other tasks usually confined to clerical work, high contrasts are relatively rare. The mail-sorter is confronted with the lowered contrasts of poor typing and writing, addresses on colored backgrounds, and window envelopes. In sewing the contrasts are generally very low, for it is commonly the aim to render the thread or stitches unnoticeable or of low visibility. The machinist working with metal is interested in scratches or other low contrasts. Workers assembling delicate parts too often see them against a dark background or a confusion of objects. Often backgrounds can be provided of the proper brightness or reflection-factor. Wood workers, type-setters and millions of others are working long hours daily with low contrasts. Throughout the work-world visual tasks are rendered more severe because of low contrasts, and controllable factors which could counteract the effects of these on visibility are persistently ignored. When one recalls that visibility rapidly decreases as the contrast decreases, it is seen that ideas of what a severe visual task is and what the desirable size of details is must be revised. And along with these must come a revision in what is considered desirable brightnesses and intensities of illumination.

It is easy to prove the great influence of contrast, if one cannot accept statements based upon recent scientific researches. One may experiment with black thread on white, gray and black fabrics, plain and patterned. One may dye part of a magazine a dark gray and try to read it under ordinary conditions where the undyed portion is not readable with any appreciable ease. One need do nothing more than observe the difficulties of seeing things under various conditions. A black hairpin may be fairly visible under the better light and brighter background of the dressing table; but it is usually difficult to find on the floor covering. The glint of a highlight may reveal it and at the same time reveal to the observer something of the factors upon which visibility depends. The proverbial collar-button is not difficult to find because it hides behind something. Notwithstanding its glint, it is of low visibility owing to other factors. Note the signs along the highway and the effect of contrast. Also note the time required to recognize something or to read a few words while speeding by. Everywhere the lessons of contrast are available.

### BRIGHTNESS

Brightness is a sensation produced by radiant energy. Without brightness we cannot see; therefore, light is the major partner of the visual sense.

In fact, seeing is largely a partnership of lighting and vision. Lighting is more than light, for it involves the proper distribution of light. The importance of these factors is so great that they are extensively discussed elsewhere. The present discussion will be limited to fundamental aspects of brightness. If we can read a telephone directory near a window in the daytime and not in the telephone booth, it is because the greater intensity of illumination has raised the brightness-level of the page so that the combined result of the various factors is above the threshold of visibility. Visibility of all objects is increased in this manner throughout a wide range of brightness.

The brightness may refer to the object or to the background, but in our most common visual tasks it refers to the immediate background or surroundings of the object. If we wish to distinguish a dot or two parallel lines on a white paper, it is the brightness of paper that counts primarily. The minimum brightness which is perceptible is very low. In this respect the visual sense is remarkable in its range. These minimum perceptible brightnesses are important usually in visibility outdoors at night, along highways, in railroad yards, and on aerial routes; and indoors on stairways, around machinery and in other places where safety is involved. Brightnesses involved in serious visual tasks are usually inadequate,

but not because they are near the threshold of visibility.

Brightness is the combined result of intensity of illumination at a surface and of the reflection-factor of the surface. A white paper reflects about 80 per cent of the incident light. It requires ten times as much light to make a dark gray paper of 8 per cent reflection-factor as bright as a white paper. Therefore, from the viewpoint of brightness as a factor in visibility, the amount of light or intensity of illumination necessary is at least inversely proportional to the reflection-factor. This fact is generally lost sight of by everyone, including those who specialize in lighting the world. In the preceding discussion of contrast it is seen that, by increasing the brightness, the critical details on a page of a telephone directory could be rendered visible. Various other examples are discussed elsewhere.

Brightness may be increased by altering the background. A removable background of white paper can be used to advantage in some cases. Painting parts of machines and portions of work-benches is a possible expedient. Observe how the bright background of the sky aids in threading a needle and how ineffective most backgrounds are at night for this purpose. A translucent glass with a light-source enclosed in a box behind it is a convenient accessory in many places.

But the background need not always be bright. If one is working with small metallic objects, such as fine wires, they are often best seen by the glint of a highlight. In such cases a black background is helpful. In seeing fine objects by highlights against a darker background, one obtains the advantage of an effect known as irradiation. This is the apparent increase in the size of an object due to the spread of the image beyond the physical boundary of the object. The bright portion of the half-moon is an example. However, a case more to the point is the apparent size of the glowing filament of a lamp. When the lamp is turned off the filament appears so much smaller that it may be difficult to see.

A digression may be of interest at this point. One may wonder why printing is not done with white ink on black paper. Besides the practical difficulties involved, there are visual factors. White letters on a black background actually would appear larger than the same letters in black on a white background. For very small details there would be an advantage in printing with white ink on black paper, if this were practicable. However, this advantage is more than offset by other factors involving distractions, eye-comfort, adaptation and visual sensibility.

If a real black background is desired, one may line a box with black velvet and use an opening

in the box for a background. Even a bag lined with black velvet is much darker than black paper. It is interesting to surround the opening in the velvet-lined box with the same velvet. The former is seen to be much darker than the latter. In fact, the range in brightness from that of the opening to that of black paper can be even greater than the range represented by the black paper and white paper.

Brightness is not always controllable by reflection-factor and, when it is, the upper limit is fixed by white surfaces. Brightness is always controllable by light and lighting and throughout an enormous range. Light and lighting are so important that they are treated in a later chapter, thereby disposing of much discussion at this point.

The most outstanding feature of brightness in the artificial world is its very low order compared with that outdoors in the daytime. Exclusive of light-sources, which need not be in the visual field, illuminated objects outdoors are not comparable with even the brightness of the sky outdoors. And usually a sunlit cloud is about as much brighter than the sky as an ordinary white paper is brighter than a so-called black paper.

In contemplating Nature, it should be noted that white areas in direct sunlight are uncommon. The portions of clouds in direct sunlight are

exceptions. Prominent in the foreground of a landscape, sand and barren earth are the nearest approach to white surfaces. In the artificial world white paper is common and it is involved in the universal task of reading. For this reason reading in direct sunlight involves inordinate brightness for a serious visual task. Still, the page in direct sunlight is of the same brightness as the sunlit surface of a cloud and certainly we are adequately adapted to such brightness. However, for serious visual work brightnesses may be annoying which are pleasant when our eyes and attention are not focused upon a serious task.

But let us see what brightnesses are encountered under artificial lighting indoors. White paper illuminated to an intensity of 10 footcandles is only about one hundredth as bright as the average blue sky in the daytime, and is less than a thousandth of the brightness of a sunlit cloud. Under intensities of illumination of 100 footcandles, which are extremely rare indoors, the brightness would be only about one-tenth that of the sky in daytime and less than one hundredth that of a sunlit cloud. Furthermore, it should be noted that reading is comfortable in the shade of a tree or porch in the daytime, when the intensity of illumination is hundreds of footcandles and often a thousand footcandles. Therefore, we need not fear that brightnesses of visual tasks,

even involving white paper, will be too high in an artificial world in which a few footcandles represent the higher intensities in general use at the present time indoors.

The influence of brightness upon the visibility of critical details is of interest as a factor in visibility. For high contrasts, black objects on white backgrounds, the threshold or minimum size visible to the best eyes decreases from 1.2 minutes to 0.63 minute, when the brightness is increased from that due to one footcandle to that due to 100 footcandles. With the same increase in intensity of illumination, the minimum size visible decreases from 15 minutes to 5 minutes when the contrast is very low. Where increases in brightness are able to effect a 3-to-1 change in the size just visible, increases in contrast produce a 30-to-1 change.

Brightness greatly influences the certainty of seeing. It must be increased ten-fold to increase certainty of seeing from the threshold to 100 per cent certainty.

## TIME

Everyone must be conscious of the fact that it takes time to see. The rate of growth and decay of sensations can be measured. Likewise, the human seeing-machine requires time to react and reaction-times are involved in seeing. Mo-

tion-pictures are made possible by the persistence of vision. Also it is generally conceded that we do not see when the eyes are in rapid motion. This is a fortunate development, because it eliminates the blurring of objects as the focus of the eyes moves from one place to another in the visual field.

If only when the eyes are at rest, the stopping-time of the eye is important. The average stopping-time of the eye is 0.17 second. In extensive tests of this it was found that the briefest interval of time that it is possible for an observer to fixate an object in order to gain an adequate visual impression varied for the most part from 0.07 second to 0.30 second. The average was 0.17 second.

The period of time available for seeing has considerable influence upon the threshold values of other factors. A critical detail of a size just visible when it is exposed to view for 0.3 second becomes invisible when the time is decreased. If an object of 50 per cent contrast can just be seen under a certain intensity of illumination when the time available is 0.3 second, the intensity of illumination must be trebled if it is to be visible when the time is reduced to 0.07 second.

If certainty of seeing for a given object is to be increased from threshold to 100 per cent certainty, the time available must be doubled.

For critical details of high contrast the threshold or minimum size visible varies from 1 minute to 1.3 minutes when the time is decreased from 0.3 second to 0.07 second. For objects of very low contrast the minimum size visible must be increased from 13 to 19 minutes when the time is decreased from 0.3 to 0.07 second.

The foregoing values and relationships are for the ideal conditions of the laboratory. As is the case of other factors, minimum time required for seeing is considerably increased by the inadequacy of the other factors. Distractions are also effective, as with the other factors, and there is reason to believe that they have more influence upon the time factor than upon the others.

Naturally, speed of seeing is more important in purely visual tasks, such as reading and particularly proof-reading, than it is in visually controlled tasks involving other reaction-times, such as movements of hands and arms. Production may be a measure of speed of seeing up to a certain point, but it becomes secondary when other factors, such as bodily movements, have attained their normal gait.

Normally, the ratio of the longest to the shortest time that the eyes require for vision is about four to one. Therefore, during the fraction of the time which the eyes must perform critical visual work, there is the possibility of changing the total

seeing-time within these limits. A gain of a few hundredths of a second may seem trivial, but in continuous visual work several of these gains are being made each second.

In many cases the eyes attain a certain rhythm or rate of working, as in the case of following material as it passes through machines. The time spent in each visual operation is a compromise between time that would permit leisurely seeing and the time allowed by the nature of the work to be done. High visibility tends to make more leisurely observation possible. Low visibility tends toward greater tension and penalizes the worker. Unless the work is imperfectly done, there may be no suspicion that visibility is low and should be improved. Again, one must conclude that production, excepting in extreme cases of poor seeing, is not a measure of visibility or of the ease of seeing. The human seeing-machine suffers abuses unknowingly and maintains production at the expense of unnecessary waste of energy and other resources.

The time required for seeing is often very important where safety is involved. Many examples in factories, on streets and highways, on railroads and elsewhere, are excellent testimonials of the value of high visibility in reducing the time required to see, when split-seconds are as long as eternity.

### OTHER FACTORS IN VISIBILITY

Other controllable factors influence the fundamental ones or otherwise affect visibility and, therefore, the ease and certainty of seeing. Some are grouped herewith and treated as physical factors, although they have important psychophysiological influences which are not mentioned. The control of these physical factors and their importance in everyday seeing are discussed in various chapters. Some of the factors which affect visibility have been grouped for brevity as follows:

*Pertaining to Eyes*

Eye-glasses correct or reduce optical defects prevalent at all ages and increasing with abuse and age.

*Pertaining to Light*

Quantity of light determines the intensity of illumination, or footcandles, and the brightness of a given object and its background.

Quality of light or spectral composition determines the color of a given object and its background. It is of some importance in respect to the optical efficiency of the eyes.

*Pertaining to Lighting*

Direction of the predominant light, or location of the dominant light-source, determines high

lights and shadows on objects and surroundings.

Lighting determines the distribution of brightness, in the visual field, which influences visual sensibility and determines the degree of glare.

Diffusion of light influences highlights and shadows and reduces glare.

Lighting for serious visual tasks is usually best when it consists of localized lighting for the specific visual task and general lighting for general seeing throughout the surroundings.

*Pertaining to Objects*

Reflecting characteristics, including color, smoothness and reflection-factor, determine their brightness and highlights.

Orientation and location of objects with respect to the dominant light or light-source are important in many ways and are made possible by localized lighting or its equivalent.

*Pertaining to Surroundings*

Backgrounds determine contrast. Sometimes these are a fixed part of the object; sometimes they are controllable in brightness and color. Plain ones are best; others introduce confusion and, to some extent, the principle of camouflage. Surroundings may be divided into immediate and general. They decrease in importance with their distance from the center of visual interest.

If too dark, they decrease visual sensibility by the readaptation necessary as the eyes look away from their primary task.

Surroundings provide mental as well as muscular relaxation and require general lighting.

*Pertaining to Distractions*

Distractions may be visual, such as a glaring light-source or highlight, a confusion background, and surroundings too bright in comparison with the brightness of the visual task.

Distractions may be muscular and mental, both of which make demands upon sense-capacity and attention. Some are involved in the work being done. Others are avoidable, such as a glaring light-source, excessive darkness of the surroundings and unnecessary noise.

## LIGHTING VIEWED SCIENTIFICALLY

Lighting consists of a chain of three links:

Production of light
Control of light
Specification of light

The first two links are sound physical sciences which have been evolving for years. The third link has been a makeshift—scarcely even an empirical one and certainly not a scientific one. Lighting is as weak as its weakest link—and so

is seeing. Such an analysis of lighting readily explains the general lack of lighting consciousness, the prevalent meager footcandles of the age of candles, the inadequate enthusiasm which lighting is entitled to, the low standing of lighting as a profession, and the general neglect of lighting.

The science of seeing is, among other accomplishments, evolving a science of lighting from a crude and, at best, empirical art. Within the science of seeing is a science of lighting specification. But it does more than this. In revealing the lighting requirements which are best for human seeing-machines, the science of seeing also dictates the production of the proper light and the proper control of that light. In other words, the science of seeing really dictates lighting in all three of its aspects.

Production and control of light are physical sciences. The specification of light is a psychophysiological science, far from complete and far more complex than any physical science can be. The presence of the two physical sciences and the lack of development and understanding of the more complex science of light specification have led lighting specialists to consider lighting as an engineering matter. But the science of seeing is clarifying the situation and lighting is now promised its rightful opportunity to serve a half-seeing world.

The appalling prevalence of eye-defects can be moderated by treating the eyes right with proper glasses, if necessary, and with proper lighting always. Generally it is neither difficult nor expensive to obtain good lighting. It follows quickly the awakening of a lighting consciousness.

## Chapter V

# EYE-DEFECTS OF AGE AND USAGE

The artificial world in which we live is the product of knowledge—and of ignorance. It is a complex structure rising out of a desire to be independent of Nature's vagaries, uncertainties and burdens. Many forces are at work in its construction and some of these are conflicting and inconsistent. No civilization is all-wise, for knowledge is never complete. The beneficence which civilization bestows upon human beings is obvious and certain if knowledge is adequate. We know more than primitive beings did; and through our greater knowledge we recognize the deleterious practices of civilization's less advanced knowledge. But our knowledge is far from complete and to future civilizations some of our bad practices will be obvious. In fact, increasing knowledge continually results not only in additions to the artificial world but in alterations as well.

The artificial environment in which we live may be eminently suited to our knowledge, ambitions and desires, but it is not necessarily best for our inherited physical being. From the viewpoint of Nature and evolution, the artificial

world is a radical and sudden change in certain known respects and perhaps in many unknown ones. It is apparent in many ways that the slow processes of evolution are inadequate to compensate for some of the rapid changes in environment which civilization has imposed upon human beings.

Coming indoors in relative ignorance, man did not know, for example, that certain benefits of outdoor sunlight were left behind. Not long ago neither germs nor the germicidal power of sunlight were known. Only recently have the ravages of sunlight starvation upon babies been discovered. Many other benefits may have been left outdoors, completely concealed by lack of knowledge. Certainly, the new approach to seeing from the viewpoint of human seeing-machines is revealing heretofore hidden penalties imposed upon human beings by the artificial world.

### NATURE'S PLAN AND MAN'S

Visual tasks were relatively easy for our more primitive ancestors and they still are in most outdoor activities. Now, much unnaturally close work is performed for unnaturally long periods by most persons in the artificial world. Prolonged close work was, and still is, rare and casual in the natural world. And superposed upon this severity of civilization's tasks are the enormous

restriction in quantity of light and its unnaturalness in quality and distribution. The results of some of these generally hidden detriments are revealed by eye-defects.

A study of eyes yields an intimate comparison between the changing mode of living and Nature's efforts to keep pace through the slow process of evolution. It is apparent that we have built our artificial world much more rapidly than Nature is able to adapt the visual organs to meet the new demands made upon them. The period during which reliable records of standardized examinations of eyes have been made is so short that it is hazardous to predict the progress which each factor is making. But certainly the evidence indicts civilization's treatment of human eyes and seeing-machines.

We are born far-sighted and, if we live to an old age without the eyes suffering too much and too permanently the penalties of civilization, we die farsighted. Between these limits is an era of nearsightedness, often imposed by civilization's tasks and in some part unnecessarily. Much of this is preventable by improving conditions for seeing. The eyes of infants at birth are products of hereditary factors and are still free from some of the defects produced by the abuses of later years. Examinations indicate that the optical axes of the two eyes are normally parallel at birth

and that the eyes of most infants are actually farsighted. They are better suited to distant vision as distinguished from near vision.

Apparently, the eyes show no inherited favorable change, through the evolutionary process of adaptation, to the relatively new conditions of the artificial world. They are still the products of the natural world, where distant vision was the predominant requirement and close work was rare and casually performed. It is difficult to conceive that, in the natural state, all the products of eye-strain and conditions of poor seeing now known could be as prevalent as they are in the present artificial world. Of course, this statement does not include the diseases of eyes due to unhygienic conditions. Without question, these are diminishing as preventive measures are developed and used. What we need is to extend similar measures into the realm of everyday abuses.

## LEARNING TO SEE

Although an infant is such a highly developed physical organism that its birth is almost in the realm of miracles, learning still has an intricate part to play in the development of this human being. It seems certain that, of the total knowledge possessed by adults, most of it has been acquired through visual experience. But, begin-

ning with birth, we must learn to do many things which eventually are done automatically and unconsciously. Through the combined experiences of the senses, a baby learns to see things out in space where they are. The various eye-movements, and muscular efforts accompanying them, eventually are automatically interpreted to aid vision in telling us something of the distance and size of objects.

In binocular vision one eye sees a picture of the external world differing somewhat from that which the other eye sees. The perfect fusion, or superposition of these two images mentally, results in stereoscopic vision which puts the third dimension into the external world. The accurate interpretation of depth, relative distance and spatial relations of objects is largely, if not entirely, a matter of learning. Early in infancy the various senses begin to supply knowledge and they continue to do so without the aid of the consciousness. During the first few years of childhood the coordination of the records of the various senses results in an interpretation of the external world sufficiently true for all practical requirements. This appraisal eventually becomes automatic, regardless of the extreme complexity of factors and processes underlying it.

It is difficult to determine with exactness the stage of progress in learning to see which a child

reaches from year to year. However, we are not concerned here with the exactness of the schedule but with the general development of the visual sense and the activity of seeing from birth to death. Therefore, a few comments are sufficient for the present purpose, provided it is understood that the time intervals are only approximate.

*At birth* the eyes are farsighted. The ability to converge the eyes and to orient them accurately must still be acquired through practice and, doubtless, with the aid of other senses. The power of accurately fusing the separate and slightly different images of each eye apparently remains to be entirely developed. At any rate, it is difficult to conclude that any ability of this sort exists at birth, because it seems so obviously to be a matter of learning which requires mental development as well.

*At five weeks* an infant has perhaps acquired more experience, relatively, than for any equal period in life. Now it is able to fixate upon objects which are more or less accidentally in its line of vision. Doubtless, the various complex functions of vision, such as convergence, orientation, binocular vision and interpretations of stereoscopic vision, are undergoing necessary preparation for development. However, mind plays such an important part in these developments it is not surprising that little progress in these directions is apparent as yet.

*At six months* convergence or binocular fixation begins to be observable and, of course, the movements of the eyes are adequate evidence that practice in orienting the eyes is under way.

*At six years* it is generally considered that the ability to orient the two eyes together and to converge them accurately in binocular fixation is fully developed. Before this period has been reached eyes are obviously immature in growth and, particularly, in function. Certainly, this is a vital period in the development of the visual sense. Now the serious abuses of civilization begin to leave their marks.

*On entering school* the first serious use of the eyes begins. Before this time, distant vision prevails and near vision is casual and not prolonged. Much advance has been made in safeguarding the eyes in school by teaching correct relation of eyes and work, by providing books with large print and by breaking up the periods of close application to visual tasks. However, school-rooms remain very much underlighted and in the homes there is a woeful lack of adequate illumination and of proper supervision in regard to the use of the eyes and to the distance at which visual work is done. Regardless of the safeguards in schools, preventable eye-defects will continue to be prevalent as long as the present widespread indifference and ignorance pertaining to eyes and seeing persist.

*Adulthood* is not reached without a large percentage of eyes becoming nearsighted. This defect continues to increase in frequency with age through the first twenty years of adult life. Consideration of this fact from various angles brings one to the conclusion that most of the nearsightedness in the civilized world can be prevented by proper attention to controllable factors in seeing.

*Advancing age* is accompanied by a gradual development of farsightedness in all normal healthy eyes. The pupil steadily decreases in size, thereby shutting out more and more light. Perhaps vision gradually fails in other respects. These changes demand better and better conditions for seeing.

### COMMON EYE-DEFECTS

From the viewpoint of eyestrain due to neglect of external controllable factors in seeing, we are concerned with certain optical parts, dimensions and muscles of the eye. The optical axis is an imaginary line passing through the center of the pupil perpendicular to its plane. It is an axis of symmetry. The distance along this line within the eye is the depth of the eye-ball. The refractive system of the eye may be considered, for simplicity, to be the crystalline lens which is located just behind the pupil and the colored iris which surrounds it. The lens should focus images

accurately upon the retina, which is spread over the rear inner surface of the eye-ball.

The ciliary muscle alters the thickness and convexity of the lens and, therefore, the accommodation of the eye for objects at various distances. Six extrinsic muscles turn each eye in its socket. These muscles must keep the eyes in accurate balance with each other and with the state of accommodation. For distant vision, usually for objects at distances of fifteen feet or more, the extrinsic muscles hold the eyes so that the two optical axes are parallel. When the eyes are accommodated for near vision, these muscles turn the eyeballs so that the optical axes converge upon the point looked at.

Prolonged convergence upon near objects strains and fatigues the extrinsic muscles. At the same time the lens must be held in proper shape for the prolonged period in order that the image of the object may be accurately focused upon the retina. The ciliary muscle tires under this strain. The unnaturally close and prolonged work may eventually produce a permanent change resulting in nearsightedness.

The normal or emmetropic eye has a depth of eyeball properly adapted to the normal focal length of the lens. Parallel rays of light entering the normal relaxed eye come to a focus upon the retina.

The optical defects of eyes, which can be corrected by proper glasses and to some extent counteracted and even prevented by improving the conditions upon which seeing depends, are

Farsightedness or hyperopia
Nearsightedness or myopia
Astigmatism
Loss of accommodation or presbyopia

*Farsightedness*, or hyperopia, is accounted for in two ways. If the depth of the eyeball is less than normal, parallel rays of light, after passing through a normal relaxed eye, come to a focus behind the retina. Therefore, the image on the retina is blurred or out of focus. The same condition results when the power of accommodation of the lens is insufficient to focus images of near objects upon the retina, even when the depth of the eyeball is normal. Actually, the ciliary muscle alters the convexity of the lens and, therefore, its focal length. Farsightedness, so noticeable with advancing age, is a result of decreasing elasticity of the lens and of impaired ability of the ciliary muscle to increase the convexity of the lens. The latter, and possibly the former, can be accounted for by the constant strain, due to accommodation for near objects, throughout prolonged periods. It is obvious that the strain of accommodation

increases with the magnitude of the defect or loss of power. This can be eliminated by proper glasses. The eyes of infants are naturally farsighted, but this diminishes rapidly during early childhood until about the eighth or ninth year, when nearsightedness or myopia begins to appear. Convex lenses counteract farsightedness.

*Nearsightedness*, or myopia, results when parallel rays entering the eye come to a focus in front of the retina. Images upon the retina are blurred. Distant objects appear less distinct than near ones. This defect may be due to an elongated eyeball, to a lens inherently too convex, or to an abnormal contraction of the ciliary muscle which controls the lens. In the case of farsightedness, the power of accommodation may be sufficient to counteract the defect by undue strain on the ciliary muscle. There is no internal mechanism for counteracting nearsightedness; therefore, there is a tendency to bring the eyes closer to the objects to be seen. This tends to perpetuate the defect and to increase its magnitude. Even normal eyes are rendered nearsighted by the generally poor conditions of seeing, which are partially compensated by holding printed matter, for example, abnormally close to the eyes. Concave lenses counteract nearsightedness.

*Astigmatism* is a common defect caused by unsymmetrical curvature of the cornea and possibly of the lens. Parallel light rays entering the eye from a distant point do not come to a focus at a point. This results in a distorted image and vision is blurred. Cylindrical lenses counteract this defect.

*Loss of accommodation*, or presbyopia, gradually increases with advancing age. Either the ciliary muscle, which alters the convexity of the lens, becomes weakened or the lens loses some of its elasticity. Even normal eyes of strong and healthy subjects have already lost some of the power of accommodation at thirty years of age. The loss of accommodation results in farsightedness. Convex lenses correct this defect.

All the defects are interesting from the viewpoint of eyestrain, which drains human resources. The severe visual tasks of civilization are already burdensome for normal eyes, but they become even more so for defective eyes. In many ways it has been proved that human seeing-machines are handicapped by defective vision. Eye-glasses should be the first consideration; but other improvements in seeing are found to benefit most of those who need them most. Furthermore, adequate conditions for seeing would prevent an appreciable percentage of eye-defects commonly prevalent.

## PREVALENCE OF EYE-DEFECTS

Statistics pertaining to defective vision reveal a high percentage of eye-defects throughout all ages. Convincing evidence shows that the prevalence varies with occupation and increases with age. Notwithstanding the natural tendency toward farsightedness as age advances, the prevalence of nearsightedness increases from grade to grade in public schools. Apparently, this increase continues into college. The same tendency is found in any investigations involving large numbers of persons of various ages. We may be thankful that the science of optometry is so well developed that errors of refraction are generally correctable. This is an excellent service to defective eyes. But we need knowledge and application of measures which prevent those defects which are preventable. Evidence indicates that the increasing demands upon the eyes do not merely reveal eye-defects; they are the cause of many of them.

One can scarcely be satisfied to concede that eye-defects are a necessary result of using the eyes. Other parts of our bodies, for example, arms and legs, develop normally with ordinary use. They get stronger by proper use; and they weaken and atrophy by lack of use. Why should eyes be an exception? Certainly every philosophical con-

sideration says they are being unnecessarily penalized; analysis of statistics and general seeing conditions support the conclusions of common sense.

The increasing prevalence of eye-defects should be a matter of concern to every owner of eyes, to every parent, employer and others who have supervision over owners of eyes. The responsibility for the welfare of the human seeing-machine begins with its most important parts, the eyes. Such concern is worth while, even if it is merely a selfish one. No matter how broad or how narrow the interest, concern over eye-defects affects the future of human beings as well as the present welfare of individuals. One who studies the deleterious results of prevailing poor conditions for seeing can readily visualize human beings inheriting half-seeing eyes through abuses now unnecessary. Certainly, the effects of such abuses must eventually be inherited by future generations.

A half-century ago, eye-glasses were a mark of advanced age. Today glasses are common at all ages and are becoming more and more common among school-children. Of course, the increasing use of eye-glasses is a natural result of this age of prevention and of the development of optometric knowledge, technique and devices. But even with this increasing prevalence of eye-glasses, many eyes remain uncorrected, thereby imposing

still further handicaps on human seeing-machines which, when they possess normal eyes, are already struggling against unnecessary odds.

Eye examinations and coordination of statistics pertaining to defects involve the question, when is an eye defective? Obviously there are all degrees of departure from the normal and there are all combinations of different kinds of defects. Optometry recognizes hundreds of measurable and correctable degrees and combinations of defects. When a group of persons is examined for eye-defects, the skill of the examiner, the refinement of the method employed, and the time available for each examination determine the accuracy of the measurements and, therefore, determine the percentage of defective eyes. A nurse examining eyes in the grade schools, with the relatively crude technique necessary for rapid examination, will not find as many defective eyes as a skilled eye-specialist who has time to do a thorough job in his office. Even the specialist must usually make rapid examinations when a large group is being investigated. Therefore, the results obtained for different purposes and under different conditions vary considerably.

One may safely assume that perfect eyes are rare. This means that practically 100 per cent of all eyes are defective. However, this assumption leads nowhere for statistical purposes. It is

more practicable to consider eyes defective when they are definitely in need of corrective glasses. This involves the judgment of the examiner, when the degree of defectiveness in any given case is near the borderline.

In the present discussion only defects of refraction are considered. The general conclusions regarding the prevalence of such defects were arrived at from individual investigations of groups and from summaries. The actual values depend upon the variables already discussed, but the generalizations are not particularly affected by them.

All surveys indicate that the prevalence of eye-defects increases with age after early infancy. One summary shows that 22 per cent of eyes in public schools are defective, and 40 per cent in colleges. Another summary which includes adults of all ages shows the percentages of defective eyes at various ages to be as follows:

| *Age* | *Per Cent Defective* |
|---|---|
| 20 | 23 |
| 30 | 39 |
| 40 | 48 |
| 50 | 71 |
| 60 | 82 |
| 70 | 95 |

A summary of examinations of large groups involving 125 separate investigations, from which

some had to be eliminated owing to obviously different criteria, provides the following percentages for normal and nearsighted (myopic) eyes:

| | *Normal* | *Myopic* |
|---|---|---|
| Infants | 6 | 3 |
| Pre-school | 10 | 7 |
| Elementary school | 64 | 9 |
| Intermediate school | 30 | 24 |
| College | 28 | 31 |

Whether or not the percentages are representative of general conditions, the trends can be depended upon. It is interesting to note that the highest percentage of normal eyes is found at the ages of children in elementary schools. The prevalent farsightedness during infancy gradually decreases until the period of elementary school. During the latter period nearsightedness begins to appear and this defect steadily increases throughout intermediate school and college. There can be little doubt that this defect is largely the result of use and abuse of eyes. Later in life the increase of farsightedness with advancing age tends to overcome the nearsightedness.

### SCHOOL CHILDREN

The increase in nearsightedness is proved by many different investigations. In a college it was found to be twice as prevalent in the upper two classes as in the lower two. In an extensive

survey in the grade schools of a foreign city the prevalence of nearsightedness increased from 10 per cent in the first grade to 33 per cent in the seventh grade of "classical" schools. In "modern" schools, in which less reading and more manual work were done, nearsightedness increased only to 21 per cent by the time the seventh grade was reached.

A record kept for 21 years showed that nearsightedness in the highest class of all the state secondary schools decreased from 25 per cent to 17 per cent. This reduction was attributed, partially at least, to improvements in lighting and in the printing of the books used by the pupils.

In cases, where a record of the degree of nearsightedness was kept, it has been found that the degree increased from year to year.

Not long after a child enters school, visual tasks become more severe by being more exacting and prolonged. Although much progress has been made in printing school books and in the daylighting of classrooms, much remains to be done toward improving artificial lighting for dark days.

In considering eyesight of school children, the conditions at home are too often overlooked. The training which teachers are given in safeguarding eyesight is not extended into the home. School children do home-work under inadequate and improper lighting and they read fine print

of newspapers under these conditions. How often one sees a child reading at home with eyes too close to the newspaper or book. Sometimes the book is on the floor and the child is lying with its chin resting in the hands and its eyes too close to the print. Besides, the intensity of illumination is much less at the level of the floor than it is near the light-source.

Although seeing conditions are sometimes far from ideal in schools, much of the damage to eyes of school children can be traced to the home. Conservation of eyesight and other resources utilized by the human seeing-machine may well begin at home. Here, visual tasks such as sewing, reading and studying are quite as severe as many encountered in the work-world. In addition, they are often performed in the evening under inadequate artificial light and after the eyes and body have been fatigued by the day's activities. Many school children average an hour or two daily in reading by artificial light in the home and 20 per cent of them have eye-defects. These are significant and related facts.

A survey, whose results are typical of others, showed that in grade schools 66 per cent of the pupils were normal in their studies and 34 per cent were retarded. Of those who were making normal progress, 15 per cent had defective vision; but of those who were retarded in progress, 85

per cent had defective vision. This is eloquent evidence of one of the penalties of defective eyesight. The same handicaps are imposed by eye-defectiveness in the work-world.

In another survey of grade schools the pupils were divided into three groups—accelerates, normals and arrests—according to their progress in school work. The percentages having defective eyes in each group were as follows: accelerates, 14 per cent; normals, 25 per cent; arrests, 32 per cent.

Experienced eye specialists can recount many cases which convince one of the far-reaching effects of eye-defects upon children. The end-products of seeing are complex psycho-physiological effects and children with defective eyes are often victims of these without the parents or teachers realizing the truth. The connection between cause and effect is often so obscured that only by careful observation and interpretation of the improvements in a child's condition, after being fitted with glasses, has the true cause been recognized.

Defective vision does not merely decrease a child's efficiency in seeing and in performing the visual tasks of school life. It retards the child in its studies, which in turn affects the child's attitude. The child may develop a serious inferiority complex, become nervous, cease to join in play, and

actually decline in health. All these and other effects have been cleared up by fitting the child with proper glasses. But glasses are only one controllable factor among several important ones which determine the difficulty of seeing. Any improvement in seeing can bear similar fruit; and when the eyes do not need glasses it is still a safe assumption that other improvements can readily be made.

In addition to the effects of defective vision upon the efficiency, health and attitude of a child, there is the cost to the school system. Each year that a child is retarded unnecessarily by defective vision is a waste of money amounting to ten times the cost of a pair of glasses. Only one of these retards costs more than adequate artificial lighting of a classroom.

### MORE HELP FOR OLD EYES

Regardless of the defects of arising from abuses, it is an outstanding fact that eyes steadily lose some of their power of accommodation year after year. The shortest distance from the eyes, at which an object can be accurately though temporarily focused, is termed the *near point.* Owing to the decreasing elasticity of the eye-lens and to the declining ability of the ciliary muscle to increase the convexity of the lens, the near-point

steadily recedes as the years pass. The approximate distance of the near-point from average eyes of various ages is as follows:

| *Age* | *Inches* | *Age* | *Inches* |
|---|---|---|---|
| 10 | 2.7 | 40 | 9 |
| 15 | 3 | 45 | 12 |
| 20 | 4 | 50 | 16 |
| 25 | 5 | 55 | 20 |
| 30 | 6 | 60 | 40 |
| 35 | 7 | 65 | 80 |

It is seen that the rate of loss of accommodation increases rapidly after the age of forty years. This is the beginning of the socalled *bifocal age.*

The near point is by no means the proper distance at which a book should be read. As already stated, the best distance, as far as the eyes are concerned, is fifteen feet or more, so that the strain of converging the eyes is entirely eliminated. However, books would have to be fifteen feet square or more which, obviously, is impracticable. Furthermore, it is usually necessary or convenient to have the visual tasks within arm's length.

It is seen that a child ten years old can focus upon a point only three inches distant. The ease with which accommodation is accomplished for very close objects may partially account for the common habit of holding a book too close while reading. This often results in permanent and progressive nearsightedness.

Some eye specialists believe that at least one-

third of the power of accommodation should be held in reserve in order to avoid undue eye-strain. Therefore, the workable near-point should be at least 50 per cent greater than the near-point. The socalled normal reading distance of 14 inches includes a reserve greater than this until after the age of 40 years has been reached for average eyes. Of course, children should acquire the habit of holding the work at a distance which will be safe and useful in later life. Notwithstanding their power of accommodation, they should develop the habit of doing close work at about 14 inches from the eyes.

It is seen in the preceding table that at the age of 40 years the near-point is about two-thirds of 14 inches. With increasing age the strain of converging upon a point 14 inches distant will be more than it should be. At about 47 years of age average eyes can just focus upon an object 14 inches distant by straining the muscles of convergence to the utmost. A person will not do this because the discomfort is so obvious. The natural alternative is to hold the object or reading matter at a greater distance. In the case of fine print of a newspaper this means that the visual size, already small at 14 inches, will be still further decreased. This makes the task more critical and imposes still further upon the human seeing-machine.

At the age of 50 years the near-point is about 16 inches and, if one-third of the power of accommodation is to be held in reserve, the object should be viewed at a distance of about 24 inches. The fine print of a newspaper is now little more than half its visual size at 14 inches. However, if the intensity of illumination is adequately increased to 100 footcandles, for example, the visibility can be maintained as high as it was at 14 inches under the common intensity of illumination of one footcandle. But this is as far as light or brightness can counteract the decrease in visual size due to increasing the distance of the object from the eye. Of course, increased size of type in the case of reading matter is a solution, but this is beyond control of the reader excepting by refusing to read small print. This means sacrificing his desires for his physical well-being. Some do this, and many would, if they knew that they were straining the eyes to the extent of future detriment as well as of immediate drain upon human resources.

After average eyes reach an age of 50 years they soon lose their ability to focus accurately upon objects held at arm's length. From then on the need of glasses can no longer be avoided if they wish to read and to perform most visual tasks. Of course, glasses should be used to aid otherwise normal eyes at the age of forty years. They readily correct the defect of farsightedness.

After the age of 55 years the near-point rapidly recedes and glasses should be increased in strength more frequently.

Other factors, such as intensity of illumination, should be utilized at all times to increase the ease of seeing; but the need for these, as well as glasses, becomes more obvious with advancing age.

### THE PUPIL OF THE EYE

Now let us consider the pupil of the eye. It automatically increases and decreases in size with a change in level of brightness or intensity of illumination. This aids somewhat while the retina is altering its adaptation. The pupils close much more rapidly than they open; therefore, they aid quickly as we pass from a darker room into a brighter one, but less rapidly as we pass from a brighter to a darker one. This matter of adaptation is an everyday experience and is usually of more importance from the viewpoint of personal safety from accidents than in the visual tasks, although it is of importance in some of these.

Our interest in the pupil at this point is in the increase in quantity of light required to counteract the effect of the decrease in size which the pupil undergoes with age. Under any given average condition of brightness the relative area of the pupil of average eyes decreases with age, as shown in the second column of the following table. In

the third column is shown the corresponding increase in intensity of illumination necessary to counteract the decrease in the size of the pupil.

| *Age in Years* | *Relative Area of Pupil* | *Relative Amount of Light Necessary* |
|---|---|---|
| 20 | 100 | 100 |
| 30 | 84 | 120 |
| 40 | 69 | 145 |
| 50 | 55 | 180 |
| 60 | 43 | 230 |
| 70 | 33 | 300 |
| 80 | 24 | 415 |

The pupils of eyes of persons of the same age vary considerably in size for the same conditions. Therefore, the foregoing can only represent average values. Assuming that these values are representative, it is seen that, solely from the viewpoint of pupil area, older persons should have more light upon their newspaper, for example, than younger persons.

The pupil is the doorway for light. Just as a reduction in the aperture of a camera reduces the brightness of the image focused by the lens, so does a reduction in the area of the pupil decrease the brightness of the retinal image. The area of the pupil is proportional to the square of the diameter. For example, when the pupil is 0.1 inch in diameter it admits only one-fourth as much light as it does when it is 0.2 inch in diameter. This means that in the former case the

retinal image is only one-fourth as bright as in the latter case. Interpreting this in terms of the brightness of an object, it means that to compensate for the smaller pupil the brightness of the object should be increased to four times its value, if the visibility of the object is to be the same in the two cases.

The effect of decreasing pupil size with increasing age can be readily counteracted by increasing the intensity of illumination. Very generally, the intensities of illumination are too low throughout the artificial world. If, by chance, a young person has only sufficient light on the newspaper to see easily, old eyes with smaller pupils due to increased age, will not have enough light to see as easily. From the viewpoint of pupil size average eyes 60 years of age should have nearly twice as much as average eyes 30 years of age. Persons 80 years old should have four times as much light as persons between 20 and 30 years old.

Doubtless there are other factors, in the general failing of eyesight and of the human seeing-machines as a whole, which require compensation by more light. It is reasonable to suppose that there may be depreciation in various internal factors and processes which affect seeing. At least, it is certain that old eyes in homes, offices, factories and elsewhere are being penalized by

inadequate seeing conditions. This is true, because even normal eyes of young adults are being abused almost everywhere throughout the artificial world by conditions far from ideal.

### OCCUPATION

It is commonly believed that the vision of persons leading outdoor lives is generally better than those of indoor workers. Statistics appear to support this belief. Those who lead outdoor lives do relatively little close work compared with many who work in offices and at other severe visual tasks throughout the work-world. It requires only casual observation of the old bookkeeper, teacher, engraver, type-setter or toolmaker to see the visible effects of years of severe visual work under the restrictions generally prevalent. Further investigation reveals that ocular defects of eye-strain increase with the demands made by different occupations.

From studies made in various occupations it has been found that the percentages of persons exhibiting ocular defects and eye-strain disorders are approximately as follows:

Hunters, sailors, soldiers, policemen, farmers, laborers, etc., less than 20 per cent.

Carpenters, servants, painters, butchers, engineers, etc., from 20 to 40 per cent.

Masons, printers, machinists, foundrymen, blacksmiths, etc., from 40 to 60 per cent.

Housewives, textile workers, musicians, telegraphers, miners, etc., from 60 to 80 per cent.

Clergymen, teachers, draftsmen, watchmakers, bookkeepers, tailors, proofreaders, etc., 80 to 100 per cent.

The foregoing values are only approximate, but they can be depended upon in demonstrating the penalties which eyes suffer from the demands of civilization's severe visual tasks. Combining this generalization with the conclusions of surveys of seeing conditions, one readily concludes that the penalties of eye-strain can be greatly reduced by improving conditions so that seeing becomes as easy as it can be.

### DEFECTIVE EYES AT WORK

It has been adequately proved that work can be increased in quality and in quantity by improving the conditions which influence seeing. The rate of production of useful work is not a dependable measure of ease of seeing, as has already been pointed out. However, if persons with normal eyes can be made to see more quickly and accurately by improvements in lighting, for example, it is certain that persons with defective eyes would be benefited at least as much. In fact, they need better seeing than normal eyes do.

Therefore, one would expect them to benefit more through improvements in seeing than persons with better eyesight. In fact, well controlled laboratory researches, involving rate of performance of visual tasks, show this to be the result of improved seeing.

A typical case involved a large number of subjects who performed a given visual task at two different intensities of illumination, 3 and 12 footcandles, respectively. All the subjects had fairly good eyesight. After the investigation was completed, the subjects were divided into two equal groups, those with the better and those with the poorer vision, respectively. It was found that the average increase in production for the group with the better vision was 14 per cent; and for the group with the poorer vision the increase was 22 per cent. None of the subjects had serious eye-defects. From this and other data and reasoning, it is safely concluded that persons with seriously defective eyesight would be aided still more than those with slight defects.

In a study of hourly earnings of a group of workers, it was found that some of the workers needed glasses. In every case, shortly after the proper glasses were provided, the hourly earnings increased.

Anyone who has been seriously in need of glasses knows by experience that, after acquiring them,

work was done more confidently and with greater accuracy and certainty. The same experiences are just as real, if not as obvious, from any other improvement in seeing. One need only to observe a blind person walking haltingly. Although he may boldly step along, one sees in his posture and manner the visible imprints of a perpetual lack of confidence which can never be entirely overcome.

We need only close our eyes and try to make ourselves walk in a familiar room, or to perform a familiar task, to experience the ultimate effects of no visibility. The difference between this condition and perfect seeing is not entirely one sudden step. Whether we are conscious of it or not, any condition of seeing, which is less than ideal, diminishes our confidence, efficiency and resources in various simple and complex ways. One need only observe a worker almost anywhere in the indoor world to note the lost motion or annoyance due to poor seeing. And if one is not convinced, he need only drive an automobile at night with his consciousness open to seeing to have from moment to moment examples of the strain, uncertainty and inefficiency produced by poor visibility.

The most difficult point for most persons to grasp is that, when one can see fairly well, still further improvements in visibility and, therefore,

in certainty and ease of seeing, can be made. It is obvious that when one can barely read a newspaper more light, for example, does improve matters. Such improvement can continue until the optimum conditions are reached. These are far above present levels. We are not sensitive gauges of seeing after the threshold conditions have been passed; however, improvements can still be made, as in the case of quantity of light, until the intensity of illumination reaches at least that near a window in the daytime with a large portion of the sky providing hundreds of foot-candles.

Those who have experienced eye-defects and the obvious improvements which glasse have made are better prepared to believe that other controllable factors can also improve seeing. For example, eye-glasses may make it possible for moderately defective eyes to see objects several times smaller than was possible without glasses In the daytime near a window one can see an object only half the size of one which is barely visible at some other place in the room where the intensity of illumination is much less.

### THE NEW GOAL

The science of vision necessarily deals with minimum or threshold conditions for seeing. The science of seeing aims to discover the best or

optimum conditions for seeing. To barely see is no longer satisfactory. The new knowledge of seeing presents a new goal—the production of conditions which enable seeing to be done most easily. To accomplish this we must be able to control the factors which are at present inadequate for seeing with the greatest ease possible. Light is the most universally controllable and neglected factor. Even after eyes are properly corrected by glasses, inadequate light and improper lighting continue to damage eyesight and to waste other human resources. These are deeply hidden because the same persons who, in scientifically conducted tests choose 100 footcandles for reading, are oblivious of the fact that they generally read under one, or at best, a few footcandles. Easy seeing is the new goal which awakens them to the prevalent abuses.

## Chapter VI

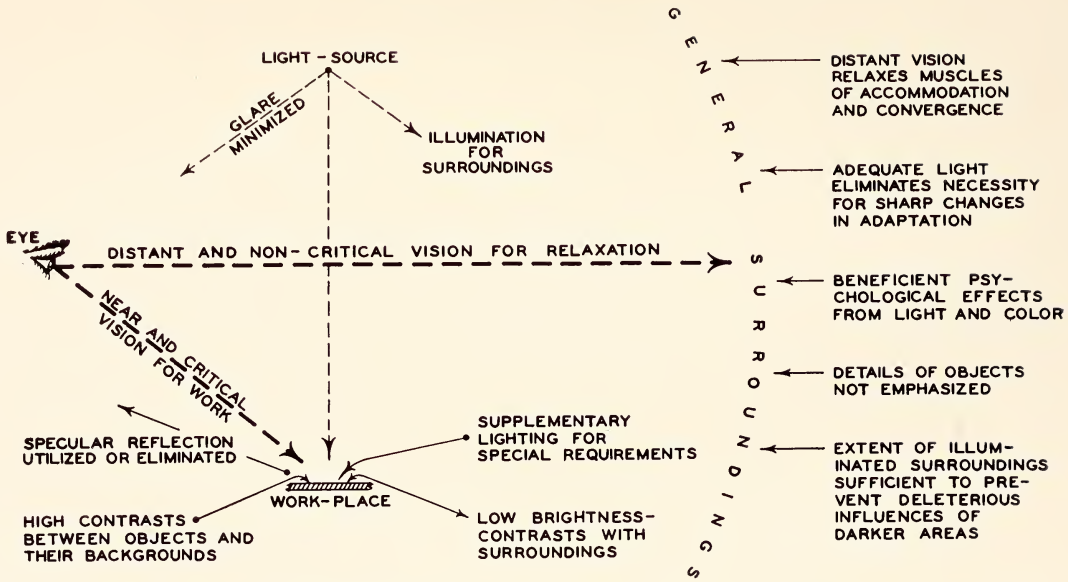
# LIGHT AND LIGHTING

Eyes are useless without light and human seeing-machines cease production when it fails. Although many secondary factors can ease visual tasks, seeing is primarily a partnership of lighting and vision. Equipped with a visual sense of extraordinary range of sensibility and a mental ability to utilize what it yields, the human seeing-machine is the most intricate organism that works. Still, it is dependent upon a controllable external factor—light—which is the medium connecting it with the things to be seen. Light is the life-blood of human seeing-machines, as it is, in various ways, the life-blood of all living things. Light is as important as eyes—and it can be completely controlled. Within certain limits eyes can be sharpened with glasses; but there are no limitations to the control of light in quality, quantity and distribution, or in any conceivable respect. Upon its control depends the ease of visual tasks and, consequently, the conservation of eyes, energy and other human resources.

### TORCH OF CIVILIZATION

Light is the servant, the companion and the inspiration of mankind. From more or less vague

## LIGHTING FOR VISUAL WORK AND VISUAL RELAXATION


LIGHT - SOURCE
GLARE MINIMIZED
ILLUMINATION FOR SURROUNDINGS
EYE
DISTANT AND NON-CRITICAL VISION FOR RELAXATION
NEAR AND CRITICAL VISION FOR WORK
SPECULAR REFLECTION UTILIZED OR ELIMINATED
SUPPLEMENTARY LIGHTING FOR SPECIAL REQUIREMENTS
WORK-PLACE
HIGH CONTRASTS BETWEEN OBJECTS AND THEIR BACKGROUNDS
LOW BRIGHTNESS-CONTRASTS WITH SURROUNDINGS
GENERAL SURROUNDINGS
DISTANT VISION RELAXES MUSCLES OF ACCOMMODATION AND CONVERGENCE
ADEQUATE LIGHT ELIMINATES NECESSITY FOR SHARP CHANGES IN ADAPTATION
BENEFICIENT PSYCHOLOGICAL EFFECTS FROM LIGHT AND COLOR
DETAILS OF OBJECTS NOT EMPHASIZED
EXTENT OF ILLUMINATED SURROUNDINGS SUFFICIENT TO PREVENT DELETERIOUS INFLUENCES OF DARKER AREAS

This is a short story of seeing, dealing with some of the more important external factors to be considered in connection with lighting and the visual task. The object should receive adequate light properly directed. If its background is controllable, it should be considered. The surroundings should be illuminated for general purposes and for relaxation of the eyes and mind. But the contrast should not be so great as to require appreciable adaptation of the eyes.

recognition of its manifold beneficence outdoors it became a god of primitive beings. This worship has become so intermingled that it persists in the highest civilizations as symbolism in religion and in the arts. But with the mastery over it, already bequeathed by modern science in the relatively enormous advances in the production and control of artificial light, general recognition of its utilitarian possibilities has not kept pace. Now, with relatively inexpensive and highly controllable light available, few are versed in, or even conscious of, the beneficence it can bestow throughout the artificial world. Naturally, lighting consciousness slumbers where seeing consciousness does—nearly everywhere.

Throughout the course of civilization artificial light has led the way. The first declaration of independence from Nature was broadcast in light and heat issuing from the controllable fire in the cave of primitive man. The heat banished the chill of night and the light was a power over darkness. Activities were no longer bounded by sunrise and sunset. Safety, comfort, convenience, leisure and home life acquired new significance. The march of civilization had begun.

Now we can look backward chronologically, or around us geographically, and appraise civilization in terms of artificial light. Crudity, inadequacy and inconvenience in this respect generally decrease with knowledge, industry, opportunity

and prosperity. Artificial lighting is more than an indicator of independence, prosperity and intellectual enlightenment. It is a measure of civilized progress in these respects, directly or indirectly.

Although it is an interesting and instructive journey, we need not go backward in time to follow the course of artificial light in its relation to civilization. We need only to see in our mind's eye the Russian peasant of the hinterlands, by the light of a fire or of a burning wood-splinter. Also the sputtering blubber in the Esquimo's hut and the desultory camp-fires of semi-savages of the tropics or of Tibet show by contrast how modern artificial light favors us. We have a 24-hour day. Modern civilized activity has no time-clock. All night long human beings are at work. Our demands for morning milk and newspapers are being filled; mail and people are traveling; civilized activities are proceeding under controllable artificial light. And better still, after the sun sets and work is done we have light for leisure, the greatest reward and, perhaps, most potent cause of civilized progress.

As great as the value of artificial light has been to modern civilization, the cost of negligence in utilizing its full possibilities is staggering. The losses in this respect have totaled billions of dollars annually over the past score of years since

inexpensive, adequate, and convenient light-sources have been available. The advance in the production of light has far outstripped the use of it. Seeing has not been understood and what little attention has been given to it is based upon inadequate premises. And light being a universal necessity for all human beings, the contribution which it makes in conserving human resources must depend largely upon the consciousness of every human seeing-machine of its importance and controllability. In the commonplaceness of light lie both the cause of indifference toward it and the proof of its universal effectiveness.

### MEASURING LIGHT

Notwithstanding the ultra-importance of light in nearly all human activities, few persons are familiar with the unit in which it is measured. Even fewer persons are able to roughly appraise quantity of light or, to be more exact, intensity of illumination. No one without the aid of a measuring device can even approach exactness in this respect. Unfortunately, if we can see after a fashion, little or no attention is given to the matter of adequacy. The new science of seeing, which is evolving, has already established the outstanding and even astonishing fact that no one, unaided by data or devices, can be a dependable seeing-meter. Many persons can, with sufficient

accuracy for many practical purposes, appraise quarts, bushels, feet, pounds, and degrees of temperature. A good deal of practice is acquired along these lines because everyone is conscious of these and, particularly, of the things that they measure. With a thoroughly slumbering consciousness in respect to lighting and seeing, a person gains no practice in appraising intensity of illumination, ease of seeing, and psycho-physiological effects of poor conditions for seeing.

The unit of intensity of illumination is just as simple as any other unit, such as a quart, but it requires a device to measure it accurately just as in measuring anything else. Nearly all common units of measure have their sources in the distant past. When modern science began, a few centuries ago, the candle was the prevalent light-source. It was logical that a candle of a certain size and content should become the standard source of light for purposes of measurement. Here, we need not bother about the specifications of the standard candle, for ordinary candles are sufficient for our present purpose.

If we place a small surface one foot from an ordinary candle so that the rays of light fall perpendicularly upon the surface, or nearly so, the intensity of illumination is one footcandle. The intensity of illumination will be the same whether

the surface is a white paper, a black cloth, a colored book cover, or anything else. However, it will be noted that these various surfaces will appear of different brightnesses. The object of light is to produce brightness; and, as discussed later, brightness depends upon the reflection (or transmission in the case of translucent objects) of the object.

Simple devices, known as photometers, are available for measuring intensities of illumination in terms of footcandles. No one can be certain of the intensity of illumination without measuring it. Considering the importance of light, such devices should be common in work-places, where the efficiency and welfare of workers are so dependent upon lighting. Considering the importance of light in the welfare of all members of a family, a simple instrument of the kind now available, can be justified economically in many homes. It costs no more than barometers and many clocks found in the homes; and it is far more important than these because nothing can be done about time and weather anyway. Besides, an inexpensive clock indicates time and the daily newspaper presents the weather forecast. Of course, we like to possess good clocks, barometers and other measuring devices and have a right to. This should apply to simple footcandle-meters and, doubtless, eventually will be the attitude toward them.

Without such a device it is difficult to form a conception of a footcandle or of the intensities of illumination ordinarily encountered. It might aid to light a candle in a dark room and to read a newspaper at a distance of one foot. This intensity of illumination is greater than that commonly encountered in many places indoors.

### INTENSITY OF ILLUMINATION

On a horizontal surface outdoors the intensity of illumination reaches a maximum of nearly 10,000 footcandles at midday on a clear day in midsummer. On an overcast day it is often several thousand footcandles; and, when in the open the intensity is as low as 1000 footcandles, we consider the day to be a dull or dark one. On sunny days the intensity of illumination in the shade of a tree is commonly 1000 footcandles and on a porch it is often 500 footcandles. Let us recall how comfortably we read on the porch in the daytime and then contemplate the penalties of performing severe visual tasks indoors for long periods daily under a few footcandles at best.

These lines are being written in midafternoon on an overcast day with rain falling from time to time. On a horizontal plane just inside the windows of the library the intensity is about 300 footcandles. This is true at each window in the entire house. On the library desk the photom-

eter registers two footcandles. The desk-lamp provides 50 footcandles of artificial light and still the intensity of illumination is only one-tenth what it is on the porch on average clear days in summer. Downtown in office buildings at present the intensity of illumination is generally lower than in my library, because adjacent buildings obstruct much of the sky. Almost everywhere in the indoor work-world artificial light is in use and the average intensity of illumination is a few footcandles; one footcandle is common.

In the daytime at home one may choose a location near a window to perform a task such as reading or sewing. If a photometer were available, it would register at least 100 footcandles and often several hundred. But when night comes and the artificial light is turned on, the same tasks are done under a few footcandles. This is because few have an opportunity to measure footcandles and, therefore, to become practiced in estimating them.

It is a very simple matter to obtain desirable intensities of illumination. In a bridge lamp there is a 60-watt lamp. About one foot from it the photometer or footcandle-meter registers 80 footcandles, and at two feet, about 20 footcandles. On replacing this lamp with a 100-watt lamp more than 150 footcandles are obtained at a distance of

one foot and 100 footcandles at a convenient distance for reading, sewing, etc. Before the mirror in the bathroom the intensity of illumination is 40 footcandles from two 60-watt lamps in diffusing shades, one on each side of the mirror at the height of the face. A 500-watt portable lamp in the bathroom provides mild ultraviolet and penetrating infrared radiation for health purposes. Three feet from it the photometer registers 1000 footcandles! How easy such an intensity of illumination is obtained and how hopelessly low the common intensities of illumination indoors really are! Such comparisons aid materially in demonstrating the value of quantities of light which are natural to us as seeing-machines, because we are still products of outdoor environment.

It is seen that levels of illumination of 100 footcandles and more, obtained easily and inexpensively with artificial light, are still meager compared with common daylight intensities, but they are far above those found almost everywhere in the indoor world. In homes low-wattage lamps are prevalent. It is difficult to find a boudoir lamp for the bedside in which a 100-watt lamp can be inserted. In railway stations, where one passes the time reading, less than a footcandle usually prevails at night. In many of the old stations this is not exceeded much in the daytime. One or two footcandles are common in pullman

cars. Many tests in rooms of the best hotels reveal two footcandles a rarity when one wishes to read in bed. Few schools have more than five footcandles of artificial light. Progressive stores, offices and factories may have five to ten footcandles and, in rare cases, 20 footcandles; but, for the most part, the artificial world is scarcely emerging from the age of candles in the intensities of illumination on visual tasks.

At least the extreme portability of a candle made it possible to place it close to the work. Often it is not easy to bring the work close to a modern source of artificial light. Intensity of illumination decreases rapidly as the distance from the source increases, in fact, inversely as the square of the distance. At one foot from a 60-watt lamp concealed in a shade there may be 50 footcandles. At three feet the intensity of illumination is reduced to one-ninth, or about five footcandles; at five feet it is two footcandles and at seven feet it is only one footcandle. Therefore, one of the most important factors is distance of the visual task from the light-sources. Electric light-sources are commonly much more powerful than the candle; but the intensity of illumination at the visual task is often greatly reduced by distance.

A 100-watt lamp may be equivalent to 100 candles; but the intensity of illumination ten feet from it is about the same as that one foot from one

candle. The candlepower divided by the square of the distance in feet gives the intensity of illumination in footcandles.

Lamps are no longer rated in candlepower; they are rated in lumens. The lumen measures the flow of light from a source. A source which emits light uniformly in all directions and supplies a total of 12.57 lumens is one candlepower in all directions. Modern tungsten-filament lamps vary in luminous efficiency from ten to thirty lumens per watt, depending upon the wattage and purpose. One lumen falling on a square foot of surface is an intensity of one footcandle.

Let us consider the question, what is the desirable intensity of illumination? The simplest correct answer is a rather useless one. Such an answer would state that the ideal intensity of illumination for serious visual tasks is approximately that in the shade of a tree, or about 1000 footcandles. To achieve this throughout the artificial world where good seeing conditions are important is not generally practicable. Therefore, no one need fear that a visual task will be over-lighted; still, there is a widespread belief that intensities of illumination can be too high.

The best practical answer to the question of desirable footcandle intensities is the recommendation that they be as far above the present meager intensities as is practicable. In other words,

the immediate problem is to increase footcandles above the present levels, which are crippling eyes, causing eye-strain disorders and unnecessarily draining physical and nervous energy. Inasmuch as the problem becomes one of economics and practicability, it is well to give particular attention to those places involving serious and severe visual tasks.

Considering economic, practical, hygienic and humanitarian aspects, the minimum recommendations may be briefly expressed as follows:

*100 footcandles or more*

For very severe and prolonged tasks, such as fine needle-work, fine engraving, fine pen-work, fine assembly, sewing on dark goods, and discrimination of fine details of low contrast, as in lace-making, weaving, darning and inspection.

*50 to 100 footcandles*

For severe and prolonged tasks, such as proof-reading, drafting, difficult reading, watch-repairing, fine machine work, average sewing and other needlework.

*20 to 50 footcandles*

For moderately critical and prolonged tasks, such as clerical work, ordinary reading, common bench-work and average sewing and other needlework on light goods.

*10 to 20 footcandles*

For moderate and prolonged tasks of office and factory and, when not prolonged, ordinary reading and sewing on light goods.

*5 to 10 footcandles*

For visually controlled work in which seeing is important, but more or less interrupted or casual, and does not involve discrimination of fine details or low contrasts.

*0 to 5 footcandles*

The danger zone for severe visual tasks, and for quick and certain seeing. Satisfactory for perceiving larger objects and for casual seeing.

It is again emphasized that the foregoing recommendations are not ideal and that they are arrived at by working upwards from the present inadequate intensities and by taking into account economic and engineering aspects. It is not impracticable to obtain 500 or 1000 footcandles when necessary, but for the present the foregoing intensities would accomplish much toward conserving human resources now being wasted.

One important aspect of the footcandle should always be involved in considerations of footcandle intensities. The effectiveness of a footcandle varies within wide limits. It is not a fixed value.

For example, when the common intensity of illumination of one footcandle is increased by one footcandle, the latter causes a significant and, if properly appraised, an obvious improvement in seeing. But one footcandle added to 10 or 20 footcandles causes only a barely perceptible increase in brightness and no noticeable improvement in seeing. In other words, footcandle intensities must be approximately doubled, if the improvement in seeing is to be really significant, and even then all its benefits are not obvious. Therefore, if one wishes to improve seeing by increasing the intensity of illumination, the latter must be increased in approximately geometric ratio. That is, a scale of footcandles, such as,

1, 2, 5, 10, 20, 50, 100, 200, 500, 1000

represents approximately successive equal improvements in seeing. A corresponding scale of visibility or of increase in ease of seeing would be an arithmetic one, such as

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

### BRIGHTNESS OF OBJECTS

The primary purpose of light is to produce brightness. A socalled white paper diffusely reflects about 80 per cent of the light which falls upon it and is said to have a reflection-factor of

80 per cent. Actually, it is not white, but light gray. It is not a perfect white because it does not reflect all the light which falls upon it. There are no perfect whites, although pure white powders may have reflection-factors of 97 per cent. A socalled black paper usually reflects about 3 per cent of the light and is said to have a reflection-factor of 3 per cent. Actually, it is a very dark gray, because it reflects some light. A socalled black velvet approaches perfect black still more closely because of the depth of the nap. Each fiber of the nap is no nearer black than a dull black paper or paint, but light is trapped in the depths of the nap and suffers additional losses by multiple reflections. Therefore, the velvet reflects only a fraction of a per cent of the light which falls upon it. As stated elsewhere, a hole in a velvet-lined box is practically a perfect black, because the slight amount of light which the interior velvet lining reflects is eventually nearly all absorbed by the internal reflections. Consequently, the hole appears blacker than a piece of velvet surrounding it.

It is seen that, for a given intensity of illumination, there may be a variety of brightnesses ranging from nearly black throughout the various grays and colors to nearly white. Examine a rug over whose surface the intensity of illumination may be approximately constant. Quite a range

of brightnesses is seen, owing to the different reflection-factors of the various elemental areas of the pattern.

Intensity of illumination, expressed in foot-candles, is important. It tells how much light is available at any surface. It determines the maximum brightness which reflecting surfaces could have. This would obtain for a surface which was perfectly white. However, brightnesses are determined by the objects themselves; and, after all, the production of brightness is the primary purpose of light.

Those who have been supplying light to the artificial world naturally think in terms of quantity of light or intensity of illumination. They are supplying a cause, and have been so intent upon this that they have not given enough attention to effect. In a sense, light is cause and brightness is effect. Brightness has entered relatively little into lighting practice and footcandles relatively too much. For example, in stores the floor-coverings should be displayed to purchasers under many times the quantity of light that chinaware is if they are to be seen as well as the light-colored china.

There are several units available for expressing brightness. The millilambert is most commonly used. A socalled white diffusing surface, such as the best white paper or powder, has a bright-

ness of approximately one millilambert when it is illuminated to an intensity of one footcandle. To be more exact, one millilambert is the brightness of a socalled white diffusing surface having a reflection-factor of 80 per cent and illuminated to an intensity of 1.16 footcandles. A diffusing surface would have to reflect 93 per cent of the light in order to have a brightness of one millilambert, if illuminated to an intensity of one footcandle.

Light and lighting have been purchased tacitly for seeing; but they have not been sold on a scientific basis of seeing, because such a basis has not been available until recently. Lighting practice has necessarily been empirical, but it should begin to develop as a science. Light and lighting have been more generally supplied as commodities than as means to the very important ends, which are seeing and its end-products affecting human welfare. Lighting specialists have confined their attention to light and eye specialists have dealt with eyes. The seeing specialist may evolve from either of these, but more likely from the ranks of eye specialists. His greatest aids will be eye-glasses, intensity of illumination, brightness and lighting.

It has been seen that brightness is a product of reflection-factor *and* footcandles in the case of surfaces which diffusely reflect the light.

All the foregoing discussion refers to surfaces which diffusely reflect light, and most surfaces do. However, a mirror does not and its brightness does not depend upon the intensity of illumination. It actually reflects images of objects, so that the brightnesses seen in it are approximately those of the original objects, including light-sources. Although most objects reflect light diffusely, some have surfaces which are smooth and shiny. In effect, these surfaces are mirrors and we may see more or less perfect images of bright objects reflected from them. This is why glossy paper is undesirable, for the reflected images of light-sources are glaring. For example, in reading print on glossy paper, the more or less mirrored images of light-sources reduce the visibility of the print owing to the glare. An excellent model for studying this effect is readily made by placing a sheet of clear glass over a printed page. The images of the light-source can be seen at certain angles. Its glare reduces visibility, is annoying, and may be harmful.

## LIGHTING

Lighting involves the distribution of light, that is, its direction and diffusion. Light involves only quantity and quality. The light falling on a horizontal surface outdoors on an average clear day consists of about 80 per cent directly from

the sun and about 20 per cent diffusely from the large area of sky. This lighting effect is natural and acceptable. The other extreme of lighting outdoors is that from a completely overcast sky. At such times there is no directed light and shadows are indefinite. All the light comes from the large expanse of sky. The effect is uninteresting and is not generally satisfying. Between these two extremes we have a variety of combinations of direct light from the sun and diffuse light from the sky. The sun is so bright that we avoid looking at it; and, there being only one sun, we can easily avoid seeing it. These lessons from outdoors should be brought indoors.

Daylight indoors is restricted by windows and its distribution is very unsatisfactory. There may be 200 footcandles near the window and only 2 footcandles ten feet away. There is no way of overcoming this disparity, excepting by skylights, and these can be applied only to one floor. The practicable solution is to have adequate artificial light available where the intensity of daylight is too low.

As efficient powerful electric light-sources became available, the ceilings of rooms were utilized as a secondary source of light. When all the light is directed to the ceiling of a room, the system is known as indirect lighting. On the other hand, if sources are confined in open pendent

reflectors, all the light is directed downward and the system is known as direct lighting. Neither system is perfect, but the totally indirect is generally better than the totally direct. The fact is that a combination of the two is ideal for most purposes.

The semi-indirect system provides a combination of direct and indirect lighting from overhead fixtures. The most common fixture in this system consists essentially of a diffusing glass enclosing the light-source. This should be large enough so that it will not be too bright to look at with comfort. From this diffusing enclosure light is emitted in all directions. The shape and transmission-factor of the glass can be controlled so as to send more light upward or downward depending upon the combination of direct and indirect light desired. Such systems are very satisfactory for stores and for work-places where the visual tasks are not severe. From the viewpoint of seeing it is not the best for critical tasks anywhere. Purely from the viewpoint of lighting for seeing it is not ideal for classrooms in schools. However, it is impracticable to provide desk-lamps in addition to the general lighting in classrooms, because the desks are so close together. Thus, compromises among various factors must be made.

The simplicity of illuminating large areas by means of general lighting from socalled indirect

and semi-indirect systems has confined practice too much to these systems. One cannot study seeing and the human seeing-machine intimately without concluding that general lighting alone does not meet the requirements in most cases. With the advancement of the sciences of lighting and of seeing, it has become more and more apparent that general lighting is necessary for general purposes and localized lighting for specific visual tasks. This conclusion is reached from various viewpoints.

Localized light superposed upon general lighting is a practicable and economic method of providing, efficiently and inexpensively, the intensities of illumination which make visual tasks as easy as possible for human seeing-machines. Localized light provides opportunities to direct the dominant light upon the work in such a direction as to best promote visibility. Advantage can be taken of highlights and shadows, for example, or they can be avoided by controlling the position of the source. Also, with a well-shaded light-source near at hand one can orient an object with respect to the light-source. Localized light provides a control over visibility which general lighting does not. Finally, there are advantages of concentrating attention where the localized light is available. The attention is hemmed in, as it were, by reducing the distractions of surroundings.

In a large office, for example, general lighting affords no escape from the great expanse of bright ceiling and the many luminous fixtures. Under general lighting the work-field cannot be the brightest and most intensely illuminated area, as it should be. Efficiency of the visual sense is reduced and, owing to distractions, the efficiency of concentration is also lowered. Individual desk-lamps wherever practicable add all the advantages of localized light to those of general lighting. If one will observe carefully the condition under which serious reading is most satisfactory at home, it will be found that the choice will be a position near a portable lamp, whose light-sources are screened from the eyes but not from the book. The lighting will consist of some indirect light from the ceiling and upper walls, but predominant light will come directly from the portable lamp. Here one may read with comfort and concentration.

Obtaining proper lighting is as easy and simple as obtaining adequate light. Lighting is really a simple matter; but seeing is a very complex one. If one understands the major factors and principles of seeing, proper lighting becomes so simple and is so easily achieved that anyone can improve seeing conditions for himself.

It has been seen that localized light, properly directed upon the work, contributes much toward

visibility and ease of seeing in ways that general lighting cannot. However, this does not mean that general lighting can be done away with. In fact, it is not only needed for illuminating the surroundings, in order to minimize danger and for other general purposes, but it increases the efficiency of vision. Eyes are directed toward the surroundings in order to relax the muscles of accommodation and convergence. Also, the worker benefits by relaxing attention at the same time. The eyes do not need dark surfaces for purposes of resting them. In fact, the necessity for readapting the retina, when looking from one surface to another considerably different in brightness, is annoying and causes the pupil to change in size, which means work for the ciliary muscle. Whenever readaptation to different brightnesses is necessary, visual efficiency is decreased. The surroundings are important psychologically and when they are of moderate brightness the effect is more cheerful.

The visual sense is most efficient when the immediate surroundings of the visual task are of approximately the same brightness as the task itself. However, they cease to have much influence in this respect outside of an area of about 30 degrees from the center of the work-field. Furthermore, it is found that the intensity of illumination in the localized area, including the

visual task, can be about ten times that over the surroundings in general without the effects of adaptation in looking away from the work being particularly noticeable.

Therefore, high-intensity localized lighting superposed upon general lighting is practicable, efficient and desirable in many places in the indoor world. The general lighting should supply at least five footcandles and in many cases much more. The localized lighting can supply, without appreciable cost, any intensity of illumination up to 100 or even 1000 footcandles.

### PREVENTABLE GLARE

All light-sources should be shaded if they are in the normal visual field. If they are overhead, they can be concealed in diffusing glass enclosures. Glare not only decreases visibility but causes eye-strain disorders and is distracting. A glaring source in the visual field, but not in the line of vision, has its image focused upon the retina. This reduces the sensibility of the retina and also visibility. The pupil tends to close and causes strain upon the muscle controlling it. Also, as a distraction, the eye-muscles are strained in overcoming the tendency to look toward the glaring source; in an analogous manner there is a mental strain in holding the attention upon the work.

The reduction in visibility is a function of the

intensity of illumination at the eye due to the glare-source. Discomfort is due to this and also to the brightness of the light-source. A 100-watt tungsten-filament lamp, five feet distant and five degrees from an object to be seen, reduces the visibility of the object as much as an 84-per cent reduction in the intensity of illumination at the object. In other words, preventable glare is costly in that it wastes light by greatly reducing the effectiveness of light for seeing. If the 100-watt lamp is moved away from the object so that it is 45 degrees from the line of vision, visibility is still decreased as much as by a reduction of half the light on the object. Thus, glare is costly in terms of the light that is paid for and is responsible for some of the waste of human resources. In many cases glare reduces visibility so that accidents occur. Glare from automobile headlamps is a common case. This is particularly annoying owing to the dark background, which is another reason why illuminated surroundings in interiors are desirable.

As noted elsewhere, the performance of visual tasks results in nervous muscular tension, which decreases as seeing is improved. The effect of glare upon nervous muscular tension has also been measured. The introduction of a source of glare results in muscular strain and nervous tension as indicated by the fingers. For example,

when the glare-source produced an intensity of illumination of five footcandles at the eye and on the work, the nervous muscular tension was as great as when the visual task was performed without glare under an intensity of one footcandle. Thus, nervous muscular tension is decreased by desirable factors in seeing and increased by undesirable ones.

### QUALITY OF LIGHT

The difference between the color of daylight and ordinary artificial light is obvious. In general colors do not appear the same under the two illuminants. Color is the result of the ability of a surface to selectively absorb and reflect radiant energy of different wavelengths. If the relative amounts of the energy of various wavelengths differ for two illuminants, the surface will not appear the same under each. Owing to this difference, artificial daylight of any desired quality is available through filters or bulbs made for the purpose.

Here we are interested in seeing and the welfare of human seeing-machines. In very special cases light of a special quality improves seeing, but in general it is desirable to have all wavelengths of visible radiation available. This insures against great distortion of colors and provides a more natural and pleasing effect.

Much research remains to be done in regard to the relative psycho-physiological effects of natural and artificial light. Some eyes endure daylight markedly better than ordinary artificial light. In most cases it is found that the artificial light is inadequate or glaring; but still there remain cases where it appears that the daylight is superior in quality to that of the artificial light. It appears logical that the quality or spectral character of daylight is ideal, owing to the evolution of the eyes, the visual sense and the entire human organism outdoors. Methods of studying these factors have not been developed until recently and few data are available. It is possible that ordinary artificial light is not ideal for any of us and that only a few particularly sensitive eyes rebel sufficiently for the owners of them to become aware of the source of the trouble. At any rate, for those who are certain of such effects approximate artificial daylight is available. However, it seems likely that quantity of artificial light indoors is far more deficient than its quality. At least, this deficiency may easily be eliminated.

On purely psychological grounds we are safer. Certainly daylight quality is satisfactory for work purposes. Even at night we are annoyed by its apparent coldness when engaged in work. However, in our homes, artificial daylight at night appears very cold, even bluish, though it is not,

and we are hurt esthetically. Furthermore, the warm yellowish light of flames has been associated with the cheer and comfort of homes since the first fire in primitive man's cave or crude hut. Therefore, yellowish light is deeply entrenched in the associations of cheer, comfort and protection with the home. This is a factor which obviously opposes the environmental influence of daylight outdoors.

If, after anyone has experimented with adequate artificial light, he still suspects that daylight quality might be better, he can easily try a socalled daylight tungsten lamp. The greenish blue bulb absorbs one-third of the light in altering the quality, so fifty per cent more wattage should be allowed. Light of daylight quality has the obvious advantage of natural appearance of colors. It is likely that it has advantages in conserving human resources. White light is a natural work-light and blends with daylight in the daytime. There has been a tendency toward the general use of whiter light in work-places and this is likely to increase.

## COST OF LIGHT

In closing this discussion light and lighting, let us pause to consider the cost of light in a monetary sense. Unfortunately, so much emphasis is placed upon this narrow part of the cost

that other costs in eyesight, health, energy and comfort are lost sight of. In other words, value is almost entirely neglected in a narrow consideration. No real progress in lighting can be made until cost and value are properly related and understood. Much of the abuse of eyes and drain upon human resources is traceable to erroneous ideas of cost as well as inadequate knowledge of value.

The electrical industry is highly progressive in many ways, still it has not taught its consumers how to compute the cost of electricity. The cost of potatoes for a family is readily computed. In fact, there is no difficulty in this respect with any commodity. Electricity is one of the most widely used commodities; but users who can compute its cost for operating any given appliance are extremely rare. As a consequence, exaggerated ideas of its cost are prevalent.

The cost of light produced by electricity is only two per cent of the cost of producing light by means of candles. Notwithstanding the great advances which have been made in our standards of living and working, we cannot afford to illuminate our artificial world with candles. The light would cost fifty times more than it does now. Still, from the viewpoint of prevalent intensities of illumination under which visual tasks are performed, we are still in the age of candles in many places and have barely emerged from it in others.

The cost of artificial light is no more than the cost of daylight indoors, when the latter is properly computed. In cases of elaborate daylighting construction, such as special roof-skylights, the cost of daylight is much greater than artificial light. Furthermore, daylight fails at least once a day and is liable to at any time; consequently, the artificial lighting system must be available at all times. Of course, we want windows to look out of and to admit daylight where practicable; but the daylight habit, acquired throughout centuries of meager sources of artificial light, is responsible for practices and attitudes not generally tenable now.

Electrical energy is measured in terms of the kilowatt-hour. The kilowatt is a measure of the rate at which electrical energy is being supplied; of course, the hour is the measure of the time during which the electrical energy is used. A simple analogy is our use of water flowing from a faucet. The faucet supplies water at a definite rate, depending upon how far it is turned on. Let this rate of flow or supply continue for a time and the total amount of water supplied is a product of the rate of flow times the hours during which the flow took place. In a sense, the wattage of the appliance, whether an electric lamp or a flat-iron, is analogous to the faucet. A 100-watt device means that the "electrical faucet" is open one-tenth as much as in the case of a 1000-watt

lamp. A 100-watt lamp operated for one hour means that 100 watt-hours of electrical energy have been used. If the time were only a half hour, the consumption would be 50 watt-hours. This would also be true if a 50-watt lamp were operated for one hour. Electrical energy is purchased by the kilowatt-hour. There are 1000 watts in a kilowatt, so 100 watt-hours, for example, equal 0.1 kilowatt-hour.

Naturally, the cost of a kilowatt-hour varies in different communities, as other commodities do. It is seldom more than ten cents. For residences at the present time it averages about six cents. Elsewhere it is usually less, owing to sound economic reasons. Besides, there is a lower rate when the consumption reaches a certain amount.

A 50-watt lamp would have to burn 20 hours to consume 1000 watt-hours or one kilowatt-hour. At five cents a kilowatt-hour this means it costs one-fourth of a cent per hour or one cent for four hours—an entire evening. At the same rate, a 100-watt lamp can be operated two hours for one cent. One can enjoy 100 footcandles for reading an entire evening or for a large part of a day at the cost of a telephone call. In many cases a 50-watt lamp can be operated six hours for one cent and a 100-watt lamp three hours for one cent.

It is easy to obtain 50 footcandles from portable

lamps, so it is obvious that reasonably satisfactory intensities of illumination can be obtained at an insignificant cost. The interest on the investment in a picture or two which hang on the wall is as great as the present cost of good lighting in the home. Everyone who will compute the cost of adequate light will find it to be insignificant compared with its value and with the value of many other things which cost much more.

### POOR LIGHTING IS A HABIT

Notwithstanding the fact that most persons have an exaggerated idea of the cost of light, poor lighting is largely a habit. Extensive tests with many persons show that 50 to 500 footcandles are chosen for ordinary reading. The average choice is 100 footcandles. They would choose many times this for average sewing. Still, these same persons in their homes and in the work-world perform severe visual tasks under one or two footcandles. Lighting has not been based upon seeing easily, because we are not capable of judging ease. Science must dictate the lighting. Without a science of seeing lighting is based upon the habit of using lamps of wattages comparable with those first introduced into electric lighting. Only the science of seeing can overcome the habit of poor lighting.

## Chapter VII

# HUMAN SEEING-MACHINES AT WORK

The ultimate results of seeing are so intricately interwoven with living that it is difficult to do justice to them in a limited space. The visual sense is the outstanding receiving-station of the human being. It constantly records the messages sent out by luminous objects in the external world. The sensibility of this station is so great that it picks up the faint messages from stars, weakened by the inconceivable celestial distances. It picks up the signals from atoms so tiny that they themselves have never been seen even under a microscope. Our interpretations of these messages from objects as tiny as atoms and as distant as stars become our knowledge of Nature and the universe. The result of seeing is, first of all, knowledge. From this, as workers, we produce saleable knowledge; as thinkers, we evolve ideas; as emotional beings, we experience feelings; and as human seeing-machines, we pay a price in wear-and-tear depending upon the difficulties of performing visual tasks. None of us can expect to appreciate the blessings of seeing as fully, perhaps, as Helen Keller can. But, for our own welfare, we should try. We can best begin by

These eyes are old, dulled by use and abuse, and equipped with glasses. They need much more light than average eyes of young adults. The science of seeing indicates these requirements. The local light-source provides an opportunity to orient the work so as to receive the full benefits of lighting in highlights and shadows. General illumination from ceiling fixtures is also necessary for general purposes.

awakening our consciousness to seeing and by devoting our minds to understanding it.

With limited space available it is necessary to omit many of the pleasurable phases of seeing. Welfare is fundamentally important and in preceding chapters the factors and principles of seeing have been analyzed and to some extent correlated with the penalties suffered by human seeing-machines. In other words, the cost of seeing, which has been neglected in research and practice, has been discussed as well as the more apparent value of seeing. The entire subject is so ramified that some of the analyses are very difficult and, perhaps, unavoidably tedious. It seems best to close this brief presentation by intimate descriptions of the human seeing-machine at work performing some of the common visual tasks. Obviously, there is an infinite variety of factors in the countless visual tasks performed daily. However, the principles involved in the common ones, with which everyone is familiar, are generally involved in other tasks. The same fundamental factors are also present in different degrees of prominence and controllability.

### READING

In perusing these lines the reader is not conscious of the leaps that the eyes make along each line. The focus of the eyes does not pass at a

uniform rate along each line. It progresses in a series of leaps not uniform in length or in any other respect. We drink water by swallows, not by a steady stream. Usually the number of movements and pauses which the eyes make in traversing a line varies from two to seven. The number depends upon the length of the line, upon the visibility of the printing, upon the familiarity with the text, upon the skill and practice of the reader and upon any other factor which influences the ease of seeing or facilitates the recognition of the words.

While the eyes are in motion they are anesthetized, in effect, for there is no blurring during the sweeps between the pauses. Therefore, if seeing is accomplished only when the eyes are at rest, the stopping-time of the eyes is important. Apparently, this is not a fixed period but varies chiefly between 0.07 and 0.3 second, the weighted average being 0.17 second. The speed of reading depends upon the duration and number of stops per line. Improvements in visibility tend to decrease both of these and, therefore, increase the speed.

In most visual tasks the object or critical detail to be seen is a relatively simple one; but reading is very complex in this respect. Groups of letters or words are recognized in a single look or "swallow." A child or relatively illiterate person reads

slowly, perhaps recognizing one letter at a time. With practice, the object ceases to be a single letter and becomes a word. When visibility is high, it is not necessary to distinguish the letters individually, but the letters still play their parts. This is evident from our experience with typographical errors and strange words.

A fine detail is seen best when it is at the focus of the eyes, that is, when it is focused in the center of the retina or fovea. Obviously, if we read by "gulping" entire words or groups of them, the letters on each side of the point of focus are not as easily discriminated as the one in the center. An appraisal of the visibility of a detail upon which the eyes are focused indicates a higher visibility for a group of letters seen at the same time than is actually the case. Therefore, this is another reason for a factor of safety greater than that apparently needed.

The reader has no control over the contrast between the print and the background; that is a question of paper, ink and printing. He has some control of visual size by holding the print nearer or farther from the eyes. Unless the type is unusually large, there will be no tendency to hold the page farther away. Usually, the tendency is to hold it closer to the eyes in order to increase the visual size so as to counteract, partially at least, the generally poor visibility. As em-

phasized heretofore, this increases eye-strain which often results in disorders and nearsightedness. Brightness is the only factor which is generally controllable. This can be increased by providing a higher intensity of illumination. The advantage of higher brightness of the page is noticeable when the print is quite fine or the contrast is low, and particularly when the eyes are defective and uncorrected to the extent that the letters are slightly blurred. Usually the blurring is appreciably reduced when the intensity of illumination is greatly increased.

Reading being such a common task, it is naturally used in researches of a practical nature. The most outstanding one pertaining to reading and the human seeing-machine resulted in the successful measurement of nervous muscular tension. This has already been discussed, but owing to its importance, will bear brief repetition at this point. A book of excellent printing in 12-point type, which is about twice the size of average type in newspapers, was read under 1, 10, and 100 footcandles by many different subjects over a period of nearly a year. The book could be read by all subjects under an intensity of much less than one footcandle. In fact, it has been read by thousands of persons under one footcandle, because this is common in many places. It was read with apparent ease under 10 foot-

candles and of the thousands of readers few read it under as much light as this. There is little doubt that any person, outside this group of subjects, read it under 100 footcandles of artificial light, because such an intensity is exceedingly rare at night, although common near windows in the daytime.

It will be recalled that nervous muscular tension, as indicated at the finger-tips, markedly decreased as the intensity of illumination increased and that the results indicated that this would continue to decrease up to the neighborhood of 1000 footcandles, the intensity of illumination in the shade in midsummer. This research is an outstanding achievement in the quantitative measurement of a universal penalty which human beings unknowingly suffer from reading or the performance of other critical tasks under the prevalent conditions of poor seeing throughout the artificial world. Even though visibility in any given case may appear to be adequately high or even perfect, ease of seeing will usually be increased by improvements in the factor of brightness or footcandle intensity.

A by-product of this research is also outstanding in its significance. Although the subjects were instructed to read for pleasure, as they would at home in the evening, and were cautioned that it was not a speed test in any sense, all subjects

actually read more rapidly under the higher than the lower intensities. This may also be interpreted as an indication that ease of seeing increased as the footcandles were increased.

The effect of contrast upon the speed of seeing is shown by a typical test. It was found that the speed of reading a well-known magazine increased 31 per cent when the intensity of illumination was increased from 2 to 24 footcandles. Some pages of the magazine were dyed a moderate gray having a reflection-factor of 22 per cent. The contrast between the black print and the gray paper, of course, was much less than for the printing on the white pages. The speed of reading was much slower for the reduced contrast, but it increased 104 per cent when the intensity of illumination was increased from 2 to 24 footcandles. The visibility of the black print on the gray background was much lower under a given intensity of illumination, owing to the decreased contrast. In the lower range of visibility, improvement in any factor is relatively more effective in increasing the ease of seeing and, therefore, the speed of reading.

From the foregoing it is seen that decrease in contrast decreases the ease and speed of reading. Usually reading matter consists of socalled black print on socalled white paper. However, a great range of contrasts between the print and its

background are met in practice. Elsewhere, it was shown that the lower contrast, due to the relatively low-grade paper and printing of a telephone directory, makes it necessary to increase the intensity of illumination about 200 per cent in order to increase the visibility of a given detail to that which it would have in high-grade typography. The products of the multigraph, typewriter, and lead-pencil are usually of lower contrast than that of the printing-press. Often these are on colored backgrounds and window envelopes are common. If one inspects the visual tasks of the mail sorter, he will find that they are commonly more difficult than ordinary reading. Contrast is such a powerful influence upon visibility that it should not be lower than necessary.

As contrast approaches 100 per cent, that is, perfect black on perfect white, the gain by increasing it or loss by decreasing it is not as important as in the lower range of contrast. If the intensity of illumination is adequate, the visibility of black print on paper slightly cream-tinted is sensibly the same as on white paper. At this point of high visibility esthetic considerations are justifiable and many prefer a white paper less than one tinted slightly yellowish or cream. The color of the background is of some influence, owing to optical characteristics of the eye. The violet

and blue rays cannot be focused accurately at the usual distance of 14 inches. This causes a slight blurring of the image.

It has been adequately proved that visual acuity or the ability to discriminate fine detail is improved by eliminating the violet and deep blue rays. From this point of view the best color for a paper, if it is not to be white, is yellow. This can be an esthetic tint, such as cream, or even a deeper yellow, such as canary. However, in the latter case the decrease in visibility due to lowered contrast might well be counteracted by increasing the intensity of illumination.

### SEWING

In many respects sewing is a visual task quite opposite to that of reading. The focus of the eyes is upon a given point and is only occasionally, and more or less casually, directed along the line of stitches. The point of focus may remain constant in location, as in machine sewing, or it may move along slowly, as in hand-work. But the chief difference between reading and sewing is the visibility of the things to be seen. Usually, in sewing, it is not desired that the stitches be conspicuous or even visible. Of course, there are many cases where the stitching serves a decorative purpose and in the extreme cases it is rendered purposely conspicuous by high contrast.

But even for decorative purposes, the stitching is purposely of low contrast. In most cases the chief object is to render the thread invisible. This means that thread of small size is matched to the color and reflection-factor of the cloth. The result is very low contrast and, therefore, very low visibility. In addition to this, many fabrics possess patterns of some kind. This adds one of the major principles of concealment by confusion of pattern so effectively employed in the World War.

The visibility of fine thread—near the threshold in size and contrast and additionally concealed by confusion pattern—is extremely low. It should be obvious that the most effective controllable factor—intensity of illumination—should be much higher for sewing than for reading. If the nervous muscular tension due to reading a book well printed in 12-point type is still measurable under 100 footcandles, what must it be under the usual conditions of sewing on dark goods! In the recommendations made in the preceding chapter, it was admitted that they were not ideal but were based upon practical considerations of working upward from the meager intensities prevalent in the artificial world.

From the viewpoint of visibility, which is closely correlated with ease of seeing, sewing upon light goods requires considerably more

light than ordinary reading. Sewing on dark goods should require many times more. Therefore, there seems to be no question that at least 100 footcandles, and preferably several hundred, should be used by anyone appreciative of human resources. Indeed, direct sunlight is not too much for sewing on dark goods.

### HIGHLIGHTS AND SHADOWS

A discussion of visual tasks could be endless and tedious. The fundamental factors and consequences of seeing have been presented. Anyone interested in the welfare of eyes and human beings should bear these in mind in any visual tasks. Experiments are before our eyes and minds at all times and it is worthwhile to develop the habit of analyzing visual tasks in terms of such factors as size of details, contrast, brightness, intensity of illumination, color, highlights, shadows, backgrounds and lighting in their various combinations and to note those that are controllable and those that are not. Some of these have been adequately discussed in previous chapters and reading and sewing deal with two prevalent and highly illustrative tasks. Therefore, there remains chiefly the consideration of highlights, shadows and backgrounds to touch upon briefly, although they have been also discussed to some extent.

Everyone can recall the annoyance of glossy

paper in reading. It cannot contribute in any way to the visibility of printed matter and is always a potential annoyance and hindrance. In working with metal, paint and other polished or glossy surfaces, the highlights are often annoying and a hindrance to vision. These specular reflections are more or less perfect images of light-sources or other bright areas. The position of the light-source with respect to the work can be such that these highlights are not a hindrance. This is one of the important reasons why dominant light from a local source superposed upon adequate general lighting is the best for critical visual tasks. The position of the eyes and the work can be controlled relative to that of the dominant light-source.

Often highlights can improve visibility. The curved surface of a fine needle always glints with a highlight. This is the chief reason for the visibility of the needle in sewing. In examining smooth surfaces of metal or paint for flaws or scratches, specular reflection is often helpful. Look at the works of a watch or the parts strewn on the work-bench and note how the highlights aid seeing and sometimes do not. Note also how shadows reveal form and convey other knowledge. If these fine objects are viewed against the ordinary wood-surface of the work-bench, place some of them upon a white paper and some upon

a black paper. Enough lessons can be gained from these experiments, combined with the knowledge of what light and lighting can do, to enable one to begin to understand and to improve any visual task encountered.

### PRODUCTION AND EASE OF SEEING

Throughout the work-world the rate of production by workers is economically important. Experience with production as influenced by visibility, combined with new knowledge pertaining to seeing, leads to the conclusion that everywhere production can be materially increased by improving the conditions upon which seeing depends. Production of workers has been found to be favorably influenced by more light, better lighting, localized light properly directed, backgrounds of uniform and proper brightness, avoidance or utilization of highlights and shadows, proper quality of light, adequate general illumination, elimination of glare, correction of eyes by means of glasses, cheerful surroundings, proper use of paint, cleanliness, orderliness and other factors. Whenever production is increased, the precision and accuracy of performance and the attitude and welfare of workers are usually improved. Notwithstanding all this, the rate of production of useful work is not necessarily a correct measure or indication of the price in

human resources that workers are paying in the performance of the visual tasks involved.

Workers are human and they have reserve capacities in energy and willingness. Unless they are on the point of exhaustion from the drain of their resources, they can still call on reserves and perform a task for a given period as rapidly and as accurately as when they are fresher in body and mind. Until a runner is nearing exhaustion, a temporary spurt is still possible. Actual tests of these points have shown that, at the end of a day's work, workers actually performed a given visual task more rapidly, more accurately and more attentively than they performed it at the beginning of the day. At the same time there was conclusive evidence of greater fatigue of eyes and body at the end of the day.

Willingness, reserve capacity and doubtless subtle psychological influences of pride, of anticipation of going home and of the approaching reward of rest and recreation and other human traits caused them to work better during the test at the end of the day than at the beginning. Tests of hourly production throughout the day show that influences due to eating lunch and other apparently extraneous factors usually militate against a gradual decrease in rate of production throughout the entire work-period. Workers develop certain normal rates or rhythms which

are probably influenced differently by hourly wage and piece-work, as well as by attitude toward tests and hidden influences of the unnormal conditions which tests cannot entirely avoid.

All the foregoing factors and the lack of adequate control make production tests difficult to perform and uncertain in their interpretation of the ease of seeing. Furthermore, there is no reason to assume that the speed of seeing determines the maximum rate of production of workers. In fact, there are adequate reasons for assuming that other factors, such as reaction-time, body movements and normal gait and rhythm, determine the eventual rate of performance of useful work.

It has been found that improvement in visibility increases production in proportion to the importance of vision. In visually controlled work the benefits of improved visibility are not as pronounced as in purely visual work, such as reading. However, some of the benefits continue to increase, as the conditions for seeing improve, long after production ceases to increase, as determined in so-called practical tests. In highly controlled laboratory researches the rate of performance of a visual task continues to increase with improvement in visibility factors far beyond the limits apparent in the usual tests made in the work-world.

Finally, let us recall the startling results of extensive reading tests made with the page vibrating and stationary, respectively. The rate of reading was practically the same in the two cases, notwithstanding the fact that the task was so extremely severe in one case that eyes became inflamed and the reader was obviously under much nervous muscular tension. The eyes and the entire human seeing-machine were penalized for their willingness. Throughout civilization they are unknowingly being penalized by the unnatural, inadequate and improper conditions found everywhere.

Because human beings have been unable to appraise the ease of seeing, they have been satisfied to barely see. This has taken great toll in wasted energy, but, unfortunately, this waste has been concealed. The science of seeing has revealed these hidden wastes and is revealing still others. Seeing means work for the human being, just as manual labor does. But, unfortunately, the drain in nervous and muscular energy is unnoticed excepting under extreme conditions. The science of seeing also reveals reasons for the eye-defects which are so common that they have been accepted as the natural result of using the eyes. A large percentage of them is due to previous lack of knowledge. The science of seeing has also introduced the idea of speed, accuracy and certainty of seeing. These are important in

many places in the work-world. They are particularly important where safety is a factor, as in shops and on the streets.

The new concept—the human seeing-machine—has in turn given rise to other new concepts. It is now known that the efficiency of the human seeing-machine is decreased if it must simultaneously do other things besides seeing. For example, noise decreases its efficacy in performing work. Operating an automobile, listening for tell-tale sounds, unwelcome noises and other things utilize some of the total ability or sense-capacity of the driver. His efficiency and efficacy as a seeing-machine are greatly reduced. A traffic sign must have a large factor of safety in visibility if it is to be as readily seen as when one is doing nothing else but looking at it. This is a sound scientific alibi which doubtless will be acceptable when the science of seeing has permeated civilization.

Everywhere throughout the highways and byways of civilization, the science of seeing is sorely needed. Much can be done to decrease the difficulty of visual tasks, but everywhere great improvements can be achieved by adequate light and proper lighting. In fact, this is a universal expedient and in most cases it is the only one which can be resorted to. Artificial light has long been the torch of civilization, but now it is revealed as a universal servant waiting to rescue

a half-seeing world from hitherto unknown penalties. Everywhere it can greatly increase the efficiency and safety of human beings and conserve a great waste of resources. From the savings accruing from easy, accurate, quick and certain seeing, the lighting bill can be readily met. This is the startling result of conservative computations.

Modern science possesses the knowledge and has produced the means for improving seeing. However, the damage to eyes, the strain upon human seeing-machines and the waste of human resources can be reduced only by general applications of this knowledge and by properly utilizing the controllable factors. Seeing is an important factor in human welfare and a half-seeing world should awaken to this fact. Consciousness must be awakened in everyone if this new science of seeing is to serve humanity fully. Seeing and human welfare is an important relationship whose intimacy has just been revealed.

## A REVOLUTION BEGINS

The new science of seeing is revolutionary in viewpoint and knowledge. Already it is revolutionizing the thought and attitude of a variety of interests who knowingly or unknowingly have been interested in seeing. It reveals new opportunities and responsibilities to eye specialists who can extend their services into the realm of

prevention. It is supplying knowledge upon which the specification and use of light can be firmly based. It reveals the need of a new profession of seeing specialists to serve a half-seeing world which has been penalized everywhere by poor seeing conditions. It reveals to electric service companies that they provide a commodity as important and essential as eyes. It extends opportunities for a variety of interests concerned with one or more of the three factors—visual tasks, eyesight and lighting—which are involved in seeing. It is awakening a consciousness of seeing which has not existed. As a consequence, human beings will eventually be conscious of the aids to seeing.

On many fronts the revolution has begun. Eventually the world in which seeing and human seeing-machines are very important will be remodeled by this new knowledge. This artificial world of civilization is built of knowledge—and in ignorance. Modern science has rendered valuable vanguard services. But it also has rearguard duties to perform. It must replace ignorance with knowledge and remodel a part of the artificial world which was built in ignorance. The new science of seeing supplies new knowledge for remodeling as well as for new construction. Seeing is important to every civilized person. Therefore, no science can be more generally important than the new science of seeing.

## Chapter VIII

## SUGGESTIONS FOR FURTHER STUDY

The foregoing chapters are easy journeys into important highways and byways of a complex subject of vital interest to every civilized human being. Seeing has been discussed largely from the new viewpoint, which reveals it as an activity of human seeing-machines. Actually, the reader has been introduced to the new science of seeing, as developed in the past decade, largely through the researches of the author and his colleagues, among whom Mr. Frank K. Moss deserves special mention as a collaborator for a dozen years.

For those who wish to pursue the subject further, two books are specifically recommended. *Seeing—A Partnership of Lighting and Vision* by M. Luckiesh and Frank K. Moss (Williams and Wilkins Co., Baltimore) contains much scientific data coordinated into a science of seeing and interpreted into applications. Besides many illustrations, a useful demonstration visual test is included as a supplement. *Light and Work* by M. Luckiesh (D. Van Nostrand Company, New York) is a companion work which develops a new foundation for lighting and deals with fundamentals of natural and artificial lighting. About

one hundred references to pertinent scientific and technical publications are included in these two books. These references should interest those who wish to pursue the subject to original sources.

Particularly important papers by the author and Frank K. Moss, which describe the results of recent invasions into the psychophysiological realm where the results of seeing are found, are:

A Correlation Between Illumination Intensity and Nervous Muscular Tension Resulting from Visual Effort, Jour. Experimental Psychology, 16, 1933, 540.

Muscular Tension Resulting from Glare, Jour. Gen. Psychology, 8, 1933, 455.

The Human Seeing-Machine, Jour. Franklin Inst., 215, 1933, 629; Trans. Illum. Eng. Soc., 27, 1932, 699.

The New Science of Seeing, Trans. Illum. Eng. Soc., 25, 1930, 15; Annals of Distinguished Service Foundation of Optometry, 1, 1932, 6.

Researches in Seeing, Amer. Jour. of Ophthalmology, 15, 1932, 801.

Those who are interested in color from the viewpoint of physics, vision and lighting should be interested in *Color and Its Applications* by M. Luckiesh (D. Van Nostrand Co., New York). A companion book dealing similarly for the first time with light and shade is *Light and Shade*

*and Their Applications* by the same author and publisher. A complete list of the author's books is printed in the front part of the present book.

Naturally a complete study of material bearing upon the subject of seeing must include eyes or, more broadly, the visual sense. Any authentic publication dealing with this subject or physiologic optics in general is suitable. A book by Adler entitled *Clinical Physiology of the Eye* (The Macmillan Co., New York) is a recent valuable contribution. *Physiological Optics* by W. D. Zoethout (The Professional Press, Chicago) is another recent one.

Much can be learned by observation, provided the consciousness is awakened to seeing and to seeing conditions. From the viewpoint of what can generally be done to improve seeing conditions, lighting is the most universally controllable factor. Therefore, publications pertaining to light and to lighting are of interest, although most of these have emphasized engineering rather than lighting in its relation to human welfare. Finally, eye-glasses are important in many cases. They are valuable crutches for the eyes in counterbalancing defects, many of which would be prevented, or at least moderated, if the present knowledge of the new science of seeing were widely distributed. The science of optics, as related to the eyes, has performed a great service

to civilization and doubtless it will do even more when eye specialists extend their viewpoint from eyesight into seeing and extend their services to include prevention of damage. This means they must follow eyes out into a world lacking a consciousness of seeing and of the important factors upon which it depends.

Thus it is seen that everyone interested in his own welfare and in that of others should be interested in any authentic information dealing with light, lighting, optics, eyesight, the visual sense and visual tasks which have a bearing upon safe, quick, accurate seeing and upon the conservation of the resources of human seeing-machines.

# INDEX


Accommodation, 112, 114
Adler, 189
Aristotle, 5
Artificial light, and civilization, 136
  brightness of, 94
  cost of, 165
  development of, 137
  value of, 138
Astigmatism, 112, 114

Bifocal age, 124
Binocular vision, 60, 61, 107
Brightness, 89
  -contrast, 73
  of objects, 149

Ciliary muscle, 111
Civilization, demands of, 13
  restrictions of, 18
Contrast, 73
  and speed of vision, 174
  of objects, 149
Convergence of eyes, 14, 60, 111

Daylight, color of, 163
  indoor-, 154
  -intensities, 143
  quality of, 162
Defective eyes, at work, 131
  prevalence by age, 118
Distance, of reading, 15

Einstein, Albert, 45
Electrical energy, measurement of, 165
Electricity, 164
Errors, refractive, 53
Evolution, 1
  of eyes, 60
Eye-defects, 103, 110
  and occupation, 130
  of school children, 119
  prevalence of, 115
  surveys of, 118
Eye-fatigue, penalties of, 131
Eye-glasses, 53
Eye-muscles, 56
  ciliary, 111
  fatigue of, 56
Eye specialists, 122, 124, 152, 185
Eyes, abuses of, 7
  accommodation, 112, 114
  convergence of, 14, 60, 111
  defects of, 4, 110
  evolution of, 60, 104, 108
  factors of safety, 32
  -fatigue, 30
  movements of, 61
  muscles of, 56
  selectivity of, 6

Farsightedness, 79, 105, 112
Fatigue, 29
  eye-, 30
  of eye-muscles, 56

Footcandle, 8
-recommendations, 147
Footcandle-meter, 143

Glare, 159

Highlights, 178
Human seeing-machine, 21, 184
adaptability of, 32
attention of, 23
at work, 168
efficiency of, 21
sense capacity of, 23
Human seeing-meters, 56
Hyperopia, 112

Illumination, and production, 26
daylight intensities of, 143
intensities of, 9, 143, 151
measurement of intensity, 141
outdoor intensities, 17
Illusions, visual, 63
Indoor daylight, 154

Kilowatt-hour, 165
cost of, 166

Light, 136
and production, 25
and seeing, 8, 161
control of, 101
cost of, 163, 164
measurement of, 139
production of, 101
quality of, 161
specification of, 101
value of, 138

Lighting, 136, 153
direct and indirect, 154
environmental, 154
for seeing, 152
general, 155
localized, 156
supplementary, 156
Luckiesh, M., 187, 188

Millilambert, 151
Modern science, 45, 185
Monocular vision, 60
Moss, Frank K., vi, 187, 188

Nature, colors of, 12
psychological influences of, 10
Nearsightedness, 105, 112, 113
myopia, 112
Nervous muscular tension, 34, 172
and glare, 36
intensity of illumination and, 39
tests of, 36
Newton, Isaac, 44

Object size, 75
Outdoor intensities, 17

Photometer, 141, 143
Presbyopia, 112
Production, and light, 25
and seeing, 180
Pupil, 54, 127
size of, 128

Reading, 169
Reflection-factor, 129
Refractive errors, 53
Retina, adaptation of, 54

Science, modern, 45, 185
  of seeing, 44, 54, 185
Sciences, development of, 45
Seeing, 22
  adaptability in, 32
  and human welfare, 169
  and production, 180
  benefits of better, 40
  complexities of, 2, 50
  -conditions, 68
  consciousness, 69
  cost of, 2, 21
  discomfort in, 57
  distractions in, 58
  ease of, 180
  end-products of, 3
  events in, 46
  -machine, 21, 184
  physical factors in, 50
  psycho-physiological effects of, 54, 181
  revolution in, 185
  science of, 44, 183, 185
  speed of, 97
  triple-complexity of, 50
Seeing-machine, 21, 184
  at work, 168
  sensibility of, 168
Sewing, 176
Shadows, 178
Size of object, 73, 75
Specialists, 122, 152, 185
  lighting and seeing, 102, 152, 184, 186
Speed of seeing, 97
Stereoscopic vision, 61
Supplementary lighting, 156

Tension, nervous muscular, 34, 173
Time and visibility, 95

Visibility, and highlights, 179
  contrast, 73, 84
  distractions in, 101
  factors of, 70, 72, 99, 171
  in reading, 169
  in sewing, 177
  of objects, 51, 70
  of printing, 172, 181
  of telephone directory, 85
  of traffic signals, 24
  time, 95
Vision, binocular, 60, 107
  defective, 118
  distant, 15
  monocular, 60
  near, 15
  stereoscopic, 61
Visual sense, 53
  factors of, 54

Zoethout, W. D., 189